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The Nation-Wide Survey of First Year College Physics

THE plan of uniform, nation-wide tests in first year college physics appears to avoid the dangers inherent in most educational standardizing schemes, while retaining their advantages. It is reasonable that this new venture is but the first of a series which will stimulate interest in and improve the quality of the teaching of college physics.

The plan seems to me to have distinctive advantages, as follows:

It will give each teacher a means of evaluating his own efforts and product, with the resulting opportunity of guided improvement. Yet it does this gently, since it does not make public the results by name of school or individual.

Being unofficial and optional, it does not curtail the freedom of any school to set its own standards and give its own examinations in accordance with its own particular and local interests.

As a sporting proposition it is "heads I win, tails you lose"; for if your school makes a fine showing, you can proclaim the fact from the house-tops, but if your record is low you can bury your shame and make a more intelligent effort to do better the next time.

Speaking for the American Institute of Physics, I am sure that this new move will be generally approved and its broader educational results watched with interest. Meanwhile we solicit the wholehearted support of all physics teachers to make this venture as successful and valuable as possible. If any doubting Thomas has been wondering whether the *American Association of Physics Teachers* and *The American Physics Teacher* have a real usefulness, he will cast doubt aside when he grasps the significance of this new proposal.

KARL T. COMPTON
Chairman, American Institute of Physics

Proposed Nation-Wide Physics Testing Program for College Physics

THE committee on testing of the American Association of Physics Teachers recommends for the coming year, 1933–1934, a nation-wide survey in the elementary course in college physics. We recognize that any attempt to evaluate achievement is surrounded with dangers, that we cannot know exactly what we are measuring, and that we must face great difficulty in interpreting and making use of the results; but the attempt, if undertaken strictly from an experimental standpoint, is enticing, even promising, and should certainly be open to no more criticism than is accorded to many similar enterprises undertaken in other fields by the social scientists. We believe that the subject matter of physics itself and the traditional course examinations afford an excellent point of departure for the kind of survey here suggested and that the principle of measurement so fundamental to physics may be applied advantageously to the results of course instruction in the field.

Why Conduct a Testing Program. Recent nation-wide testing programs conducted under the auspices of the American Council on Education have disclosed the fact that of 138 college averages on an English test, 23 were below the average of twelfth grade independent schools, 27 were below the tenth grade median, and 10 were below the ninth grade median; that enormous variability obtains in all colleges on science, language, and culture tests so that even the best colleges have some very poor students and the poorest colleges have some very good students; that large departmental differences exist in the same colleges; and that extensive overlapping occurs in the distributions of means of accredited and non-accredited colleges.

The inference is that similar differences may obtain in physics. If these differences are shown to exist many interesting and helpful things can be deduced from them without threatening the art of teaching college physics with the deadly blight of standardization. For example, tests are now generally conceded to be most significant for educational guidance, not merely for passing of failing students. Consider the exceptionally gifted student, the one who is made to live down to mass standards by the ordinary classroom procedures. The extent of his ability may be unevaluated unless he is measured against students other than his immediate classmates. In 1932 about 15 colleges and universities gave the same test in physics to 1000 students. The highest score was made by a man who had not been recognized in his own class as unusually gifted. Further study of his case verified the accuracy of the test rating.

In addition to serving for guidance the proposed testing program may throw some light on the complex problem of transfer students. The variable standards of individual colleges should be studied; and regardless of whether they are ever made uniform, it is important that some common unit of measurement be used for purposes of transfer from one college to another.

The Tests. The examinations selected for the survey are the *Cooperative Physics Tests for College Students:*

I. *Mechanics, Heat and Sound and Wave Motion,* 12 pages, total time 90 minutes.

II. *Light, Electricity, and Modern Physics,* 12 pages, total time 90 minutes.

Dean H. E. Hawkes has pointed out that "The minimum steps required by good practice for producing five equivalent forms of a 200-question test are the following:

1. Survey the field to be covered.
2. Construct 1500 questions.
3. Edit these, eliminating about 300 questions by inspection.
4. Print five 240-question lists, as nearly balanced in subject matter and as nearly equivalent in difficulty as possible, by inspection.
5. Administer each of these lists to about 500 representative students, giving them in pairs, to the same students, for example, *AB*, *AC*, *AD*, *AE*.
6. Score the 2500 preliminary question lists
7. Analyze the difficulty and validity of each of the 1200 questions.
8. Choose 1000 best questions.
9. Divide 1000 unto five balanced and equivalent tests, that is, Forms *A*, *B*, *C*, *D*, *E*.
10. Administer again in pairs to insure equivalence, to test reliability and validity, to correct and complete keys, and to secure adequate norms."

The proposed tests have been constructed by individuals recommended to the Cooperative Test Service, because of their interest and experience in this matter, by almost exactly the procedure outlined as ideal by Dean Hawkes. A survey of 13 texts on college physics gives the average space alloted to mechanics as 26 percent; since 200 items were to be used over the whole field of college physics, 54 items were given to mechanics. Mechanics was subdivided into 18 topics such as units, vectors, work and energy, friction, rotary motion, etc. The textbooks used 2.52 percent of mechanics to discuss simple machines; hence two test items were used for that section. The topics acceleration, effect of forces and work and energy had textbook space of 3.14 percent, 3.28 percent, 2.63 percent, but because of the importance of these topics test items were introduced in the numbers of 4, 4 and 6 respectively. The rest of college physics was treated in a similar way. The method used in allocating the items may be open to objection but no better way was known.

A study of thousands of high school tests in physics has shown conclusively that the high-scoring students are not those who know a little about many things, but those who know thoroughly the basic principles of physics and can apply them to situations. Following this lead, the makers of

the examinations have tried to avoid items that involved out-of-the-ordinary information. The items are as far as possible non-controversial and hold closely to basic considerations in college physics.

Comparability. One reason for selecting the tests mentioned is that new and comparable forms will be available each year so that annual testing may be inaugurated and carried on by departments if the results of the present experiment justify such a program. Comparability has long been fundamental in exact sciences and is fast coming to the front as a factor in measuring the results of instruction. In the Fahrenheit thermometer, the units and zero points on the scale are equal throughout, but the zero point on the scale does not correspond with the zero point of temperature. Hence 100°F is not twice as great a temperature as 50°F. This illustrates the limitations of scales that are equivalent, but which have arbitrary zero points, as the Cooperative Physics Tests have.

The Fahrenheit scale is not *equivalent* to the Centigrade scale, but they are *comparable*, because we can compute what a reading on one means in terms of a reading on the other. Zero points and degree units are both arbitrary and differ the one from the other but the results are comparable. The same thing is true of instructional tests. Thus it is not necessary that tests be equivalent, but merely comparable in order that we may measure change. Now this is especially important in a nation-wide testing program because the production of more than two or three *equivalent* tests in each subject matter is practically impossible, whereas the production of comparable tests is possible, though quite difficult and expensive. All that is necessary is that we establish the relations between the zero points and units of two scales in order to make them comparable. The essential characteristics of good units and zero points are stability and recognizability. The most stable zero point in test scales is the *mean*, and the most stable unit of measurement is the *standard deviation*. Thus to make two tests comparable we reduce the raw scores on both to standard deviation units reckoned from the mean of distributions of scores from the same or comparable groups.

Classes to be Tested. The plan calls for the testing of all students in the general course twice during the year, once at the close of the first semester and again at the end of the second. The purpose of such distribution is to make possible a study of growth over the period in question. For additional comparisons it might also be advisable to test advanced classes similarly. This feature, however, is merely suggested. Even though considerable variability may obtain in departments relative to the content of the first and second semester courses, it is urged that both parts of the tests be given each semester since the objective of the survey is to determine not only what is learned during cources but what is learned and digested independent of instruction.

If certain departments find the complete program too elaborate, Part I may be given at the close of the first semester and Part II at the end of the second, or any other combination may be used as desired. It is not expected that every department will desire to carry out the ideal program.

Scoring. Keys and directions for scoring will be furnished with the tests so that each department may do its own scoring; the committee, however, will provide such service at cost plus shipping for departments desiring it.

Collating the Results. The committee will collate the results and will publish a report in *The American Physics Teacher*. Forms for reporting results to the committee will be furnished with the tests. *These reports will be considered strictly confidential.* No department will be identified in the final report in terms of its rank on the tests. Such information, if released at all, will be made available only to the head of each departmental group and then only for his own department.

Cost of the Tests. Costs will be prorated. It is estimated that both tests for both semesters will not be more than 15 cents per student. The figure is based on the assumption that 10,000 sets will be ordered by January 1, 1934, when the tests must go to press. If larger numbers are ordered, the saving in printing costs will reduce the charge. *The estimate does not include shipping.* Departments not using both tests will have the costs correspondingly reduced.

Collaboration. The program outlined above is inade possible through the joint action of the Committee on Tests of the A. A. P. T. and two agencies of the American Council on Education, the Cooperative Test Service and the Committee on Educational Testing. The tests recommended are sold approximately at cost according to the terms of a half million dollar grant of money to the American Council.

The committee on tests of the A. A. P. T. undertakes full responsibility for directing the program but has secured the aid of Dr. F. S. Beers, Secretary of the Committee on Educational Testing, University of Minnesota, Minneapolis, who will represent that committee and the Cooperative Test Service. Further information about the program and detailed directions will come from him.

Respectfully submitted,
THE COMMITTEE ON TESTS OF THE A. A. P. T.
H. W. Farwell
C. J. Lapp, *Chairman*
Frederic Palmer, Jr.
John T. Tate
A. G. Worthing

Objective Tests in Physics[1]

H. W. FARWELL, *Department of Physics, Columbia University*

SO much has been written on the subject of objective tests that there would be no reason for adding this paper to the literature if it were not for the fact that most of the material has been published in administrative and educational journals and consequently has not come directly to the attention of those who are interested primarily in subject matter. Accordingly this article has been prepared from a subject matter point of view and for the attention of those who are concerned with the teaching of a definite subject.

It is an anomalous situation that the chief proponents of objective tests have been mostly specialists in administration and in educational methods, and it is no less strange that so few of those competent in subject matter have given attention to this problem. The result is that many objective tests in physics have been so inaccurate and inadequate from a physicist's standpoint that college instructors have felt skeptical about them. While no one pretends that objective tests are a panacea for all the ills of teaching, it certainly is unwise to neglect a good tonic because it has been put up in badly shaped containers.

An objective test is characterized by a minimum requirement of pencil driving on the part of the examinee. By putting questions in a form which permits a unique answer expressible by a single symbol, a large amount of subject matter can be covered in a much shorter time than is possible with the traditional type of test. In addition to its advantage in covering ground, the objective test permits a definite and indisputable basis of comparison, a positive bar against attempts to conceal ignorance with verbosity, an easily controlled probe for specific information, and a welcome relief to the weary reader of many commonplace examination books. Not all of these advantages may be apparent on a given occasion, but experience indicates that they exist; and one or another may be a sufficient reason to justify the use of such a test.

There are numerous forms of objective test questions, those which have been most used in physics being the true-or-false and the multiple-choice varieties. The true-or-false form is good provided that the statements can be phrased without ambiguity. According to experience it is even more difficult to prepare such a form than any of the others; for that reason more of the recent tests have been of the multiple-choice type. The multiple-choice type can be more easily prepared, but it should be noted that to make it really of value the number of choices should be made large enough to eliminate the chance of success for the mere guesser, and the options should be in such form as to seem equally likely to the uncertain student. Professor C. J. Lapp, of the University of Iowa, has used the term "multiple-situation" to designate the type more clearly and to emphasize the desirability of supplying a situation which calls for careful discrimination. In providing multiple situations it is clear that two choices give little latitude, and that a large number causes confusion even if they are all of equal value. Generally five choices seem to be a satisfactory number, although it adds little to a question to obtain these additional choices simply by adding statements that will appear ridiculous even to a moron. Yet one cannot be dogmatic about what is and what is not ridiculous; frequently good students accept as satisfactory an answer that rolls well on the tongue or sounds plausible; in other words, the "decoy" has served its purpose.

That physics is a subject less in need of examination reform than most others is attributable to the fact that the traditional examinations have considerable in common with the

[1] It is a pleasure to offer my thanks to Professor Ben D. Wood with whom various points of this article have been discussed and whose sane attitude toward testing in general has been a constant encouragement for a long period of years.

newer objective tests. Moreover, a subject like physics, with its careful definitions, its well organized principles, and its ubiquitous problems is very well adapted to afford an application of the objective test for experimental purposes. In fact, most good physics teachers of past generations probably have used many questions that could properly be classed as objective. What then more appropriate than to continue the experiment?

Much praise is due to those who have felt that the problems which are commonly given in physics tests are the only adequate measure of knowledge of the subject. Yet it is conceded that in an examination period of three hours it is possible to give only a few problems. And while these may all be important they can be hardly sufficient in number to test the student's whole achievement in physics. Furthermore, there is the question of how much time the student spends in thinking about actual physics and how much time he spends on the incidental arithmetical and mechanical operations. If one wishes to test ability in solving problems, by all means use problems, but there are students who do poorly on the problems usually given in examinations whose knowledge of fundamental physics is far from nothing.

For example, not all brilliant analysts are mathematicians; among students, there are logical minds that keenly appreciate fundamental principles but for whom mathematical analysis is not the highest form of intellectual activity. A problem stated in mathematical terms leaves such individuals cold, whereas a few qualitative questions would serve to establish the fact that they understand far more of the situation than some others who react more easily in the presence of an algebraic equation. This is not saying that great physicists use no mathematics but merely that the quantitative problem is not without disadvantages for the general student. In any event the objective test is attractive for the formulation of either type of question.

At the same time one must admit that there are disadvantages for the physics instructor who considers using such tests, the most serious being the labor involved in preparing an examination which has so few flaws that the results are not influenced seriously by them. It will do no harm to admit that much of the dissatisfaction with objective tests has its roots in the fact that the questions used were not good ones; and it may be of some value to point out the arduous nature of the task which confronts anyone who really has the urge to make a reliable test.

First of all, what is the ground to be covered by the test? This must be definitely noted, as well as the matter of the type of question to be offered. How many questions should be made on each topic included in the test? Is the test to measure the student's knowledge of the fundamental and significant facts of physics, as well as his ability to use such knowledge, or is it to take knowledge for granted and measure only the ability to analyze, to combine, and to meet new problems? Most experienced teachers know that knowledge cannot be taken for granted, and that the sampling of knowledge incidentally involved in the few problem questions that can be given in an examination period is not adequate. Hence it is reasonable to suggest that a considerable number of questions will be included that measure knowledge and understanding, along with the more involved problem questions. Roughly speaking eighty to one hundred questions of the multiple-choice variety are appropriate for a sixty-minute test. Longer or shorter tests should maintain about this proportion, with the understanding that a test beyond two hours in length apparently is too severe.

With the general scope of the test in mind and the number of items to be prepared already determined, one may then proceed to write. Here it is best to assume that the examiner has the plan well in mind, and can supply his own ideas, but his skeleton plan should be adhered to. If there are to be, say, six questions on various aspects of linear expansion, he writes at least twice that number, and, if the test is of multiple-choice variety, it will save time to write the correct answer first, leaving until later the matter of "scrambling" the decoy answers. A teacher who has read many student examinations will usually have plenty of material from which to frame the incorrect statements. But none of the answers should be very long, and so far as possible at least one incorrect answer should be nearly as feasible in the same form as the correct one. Double negatives and double-headed state-

ments should be used with caution, since experience has shown that they are not keenly discriminating. Examples of double negative and double-headed statements are: "A solution is generally nonconducting if the solute (1) does not ionize, etc."; "The electrical resistance of a wire of uniform cross section is proportional (1) to its length and the reciprocal of its cross-sectional area; etc."

The first draft should be laid aside for a period after it is completed, to be edited roughly by the writer after his fury of writing has abated. Then he may take it up with the idea that he is to look for possible errors and sources of misunderstanding. He may eliminate at once those questions which now seem to have no bearing on his purpose. Ambiguous or bad items can be struck out, for the reading of the material frequently shows that questions which seemed to be good at the time of writing later turn out to be pointless or unanswerable. If the author now feels that he has something fairly satisfactory, he should call in a critic, a colleague if possible.

Conference between author and critic will educate both, and incidentally serve to eliminate many questions as purposeless, too easy, too hard, improperly answered, badly phrased, and so on. Furthermore one needs to keep in mind that one can hardly be justified in presenting to his students a situation about which he and his colleague are in disagreement. If a fellow-conspirator does not readily grasp the plot, it is not likely that an immature student will be successful.

The questions which have survived the criticism of both author and colleague may now be assembled, the answers scrambled and put into convenient form for a preliminary test. At this point a group of instructors, assistants, or graduate students is a great asset. Most of them are quite eager to have an opportunity to criticize, and they should be encouraged to exercise that privilege freely. The result of this general criticism tells something about the group to be sure, but that should be forgotten since one is making a test and is not to assume yet that it is so perfect as to cast shadows of doubt upon the wisdom of critics. At any rate the writer will learn something more about his test and can readily make changes and adjustments which will bring the material into much better shape. He must needs be patient and calm in judgment; the whole procedure is for him quite a test of character as well as scholarship.

With this preparation one may feel that it is safe to use the result as a class examination, though the preliminary work is hardly sufficient to warrant its use as a final examination. In one sense the job has only just been started, even though the material has survived criticism and comment. If one is really interested in preparing a thorough examination, he will now analyze his questions in the light of the results obtained with students. Why should a perfectly good question be answered incorrectly by 80 percent of the upper quarter of the class, and correctly by 80 percent of the lower quarter? The answer to this is probably not known, but it is at least reasonable to say that such an item in an examination is not of much help in differentiating good from poor students. While the difficulty may rest in an unfortunate word, or even punctuation, this item which raises the goats and lowers the sheep should be eliminated as far as future use is concerned. By this means one may finally assemble satisfactory tested questions which are worthy of a considerable degree of confidence.

Particular attention should be given in the final selection of test items so that there will be at least as many questions which are problems in thinking as those which assay mere information. By way of illustration of a difference between questions consider these two which appeared contiguously in a general science test and were both unreservedly denounced as pure memory questions by certain highly reputed "thinkers."

1. The approximate average distance in miles of the earth from the sun is (1) 50,000, (2) 100,000, (3) 150,000, (4) 93,000,000, (5) 100,000,000 ....( )
2. The approximate average number of miles per day the earth moves in its orbit is (1) 100,000, (2) 150,000, (3) 200,000, (4) 1,600,000, (5) 1,000,000,000.( )

The charge that the first question is purely informational is freely admitted. As a matter of fact, however, the first question was included in the test precisely because it was considered so easy that at least 99 percent of the students would answer it at sight; in fact, 98.5 percent did answer correctly. It was introduced as a

means for clearing the ground for the second question—to insure that each student who grappled with the second question would have in mind the approximate radius of the earth's orbit.

The charge against the second question was that it was purely informational, so recondite that not even trained astronomers would carry such an item in their minds, and that trained astronomers neither could nor would answer such a question. A little more careful scrutiny, however, will indicate that the question is not at all a memory question but a real challenge to thinking ability. Having just been reminded in question No. 1 that the radius of the earth's orbit is 93 million miles, a student capable of thinking is likely to recall the simple relation $2\pi r=c$. Discarding fractions generously, he leaps to the certain conclusion that $2\pi r$ is between five and six hundred million miles. Then he joyously recalls that, according to both elementary and secondary school teachings, the earth accomplishes this stupenduous journey in one year, and that a year has approximately 365 days. A simple process of cancellation reveals the daily orbital motion as between one and two million miles, which leaves no doubt as to which of the five choices should be marked as the correct answer. It should be noted that the question does not tax a student's computing skill or accuracy; even a gross arithmetical mistake would not penalize the student who really understood the problem and who has the constructive thinking ability to solve it. It should also be noted that the facts and constants required by the problem are such as are to be expected in the minds of high-school students who have had the normal curriculum.

The point to remember here is that the external appearance of a question does not always or even usually indicate either the nature of the quality or qualities which it differentiates or its difficulty to the students. In the last analysis, and without any disrespect for the ingenuity of test and question makers, the value of all examination questions should be submitted to experimental verification.

All this discussion of the preparation of test materials has been presented for the benefit of those who are curious to know how the operation is carried out, and may be of service to those called upon to criticize objective tests in the making. But the ordinary use of tests thus constructed is in a way only a small part of the service which they may render. Perhaps one of the most puzzling problems which comes to the physics professor with regard to individual students has reference to placement—there is the freshman who wants to register for the second course when he has not offered physics for entrance, the student transferring from another institution where the arrangement of courses is quite at variance with the one locally in vogue, and even the student presenting himself for graduate work. More and more such problems are being solved by the use of standardized objective tests.

Another advantage for physicists is offered by the fact that various groups can be compared without involving the personal equations of the instructors. Student opinion is quite sensitive on the matter of instructor judgment; some instructors grade severely, and some are amazingly lenient. An occasional objective test has proved to be of great value in adjusting these differences within a department. The much larger differences between departments in different institutions can be ascertained and fruitfully studied by a widespread cooperative use of carefully constructed objective tests which have been made comparable.

In fact there is no limit to the comparison of widely separated groups, provided only that there be prior agreement on the content and scope of the test and that alternate forms are available. There have been some very important widespread testing programs in which these points have been brought out. The New York State program in 1925 included high-school physics as one subject of the test. In this case there was a definite advantage in having the well-planned Regent's syllabus as a basis. As a result there were established many definite facts about physics teaching and the method of scoring papers.[2] Again the Pennsylvania Tests[3] given in the colleges of the state in 1930 marked a praise-

[2] Ben D. Wood, *New York Experiments with New-Type Tests*, The Macmillan Company, 1927.

[3] See the *Bulletins* of the Carnegie Foundation for the Advancement of Teaching.

worthy move in college education. And during the past two years nation-wide examinations of college sophomores have been conducted by the Committee on Educational Testing of the American Council on Education.[4]

Perhaps most significant is the increasing appreciation of the value of a set of comparable tests, not merely as teaching adjuncts but also in directing and advising individual students. Such tests make it possible to measure the growth of the individual in terms of his achievement in given subjects and thus furnish a basis for advising him to continue or to abandon particular kinds of course work or to set for himself a professional objective. In a very real sense the tests can yield a quantitative index of effectiveness in education both from the point of view of the student and the teacher.

Taken all together there is plenty to justify the interest which the American Council on Education is taking in a wide range testing program, and quite enough reason for the existence of the Cooperative Test Service, sponsored by the Council. This Service has already been proceeding effectively under the able direction of Professor Ben D. Wood, and is responsible for numerous objective tests in various fields. The *Cooperative Physics Tests for College Students*, for example, are intended to measure "knowledge of and ability to think in the materials of physics." Professor Worthing's article in a recent number of this journal[5] is certainly a definite answer to any who may have felt that objective tests were bound to be tests involving the exercise of memory only. The same article also shows how unfounded is the common belief that objective tests are too simple or necessarily very easy. As physics is presented today, a test of knowledge and information is essential but is not sufficient. As for measuring sheer thinking ability, without reference to subject matter of any kind, that seems to be in the same category as the idea of temperature in a space wholly devoid of matter.

Realizing the advantage of group support Professor Wood last year invited the American Association of Physics Teachers to participate in the physics program of the Cooperative Test Service with the result that a committee on tests was appointed under the chairmanship of Professor C. J. Lapp. In this way the Cooperative Test Service is able to secure the criticism and advice of the A.A.P.T., while the Association has the advantage that it does not have to face the troublesome problem of financing a large-scale testing program. The general advisability of wide testing has been demonstrated in many subjects, and it is certainly to be hoped that the cooperation which has been initiated may continue.

Finally, it may be helpful to suggest references to earlier experiences in physics as a means of clearing up doubts, or as a way of making possible mistakes less likely. A complete bibliography is unnecessary, in fact ill-advised, but the following selected list affords good material for teachers of physics.

References

H. W. Farwell, *The New Type Examinations in Physics*, Sch. and Soc., March 15, 1924.

B. D. Wood, *Measurement in Higher Education*, World Book Company, Yonkers, New York, 1923. (Especially the chapters on physics tests.)

Lindquist, Lapp and Schindler, *Iowa Academic Contest Circular for Physics*, 1933.

A. G. Worthing, *Usefulness of Objective Physics Tests of the Reasoning Type*, Am. Phys. Teach. **1**, 6 (1933).

Reprints of the following articles on tests may be secured by writing to the Committee on Educational Testing of the American Council on Education, F. S. Beers, Secretary, University of Minnesota, Minneapolis, Minn:

B. D. Wood, *Basic Considerations in Educational Testing;* E. P. Wood, *Examining the Use of Examinations;* Max McConn, *The Cooperative Test Service;* Max McConn, *Educational Guidance is Now Possible; Reports of the American Council Committee on Educational Testing on the 1932 and 1933 College Testing Programs*, Educ. Rec., Oct., 1932, and Oct., 1933.

[4] Educ. Rec., Oct., 1932; and Oct., 1933.

[5] A. G. Worthing, Am. Phys. Teach. **1**, 6 (1933).

Some Indispensable Requirements of a Rational Treatise on Physics, and Their Practical Realization

G. F. Herrenden Harker, *Department of Physics, University College, Cardiff, Wales*

PROGRESS in any science must be largely conditioned by past achievements in its own, and in related fields. The rate of expansion in almost all branches has, however, become so rapid that there is an increasing danger that the sheer mass of material may overwhelm us rather than inspire us towards fresh interpretations, and guide us to new developments. The potential effectiveness of our scientific heritage is to be gauged not so much by its bulk as by its availability. It becomes, therefore, a matter of fundamental concern that we should be enabled periodically to take stock of our definitive acquisitions, have their values assessed for us and the findings presented in an accessible form. The data of physics can be disinterred from the relevant literature by anyone possessing the necessary facilities, and a sufficiency of acumen and tenacity. But the problem of correlating so diversified a store of information, of extracting the essence of so many isolated contributions, and linking the residue into a unified exposition, in a comprehensive treatise on the subject, involves a labor of unparalleled magnitude. It demands so rare a courage, and so exceptional a competence, that few physicists are likely to combine in their persons the qualifications needed to face so stupendous a task. It is rarer still to find it carried to a successful conclusion, though this has recently been accomplished by one of the most outstanding among contemporary teachers of physics, Professor H. Bouasse, of Toulouse. His work, under the title of the *Bibliothèque scientifique de l'ingénieur et du physicien*,[1] consists of forty-five octavo volumes, each of four to five hundred pages. This is the most comprehensive and important collective work on physics ever written by one man. It represents a singularly impressive contribution to science, and incorporates features of special significance towards certain of which attention will now be directed. Many of the remarks which follow have been adapted from Professor Bouasse's own writings. I desire to tender to him my grateful thanks for allowing me the privilege of using them in this connection.

Since the data of physics are, implicitly at any rate, a common possession, the main difference between one text and another will reside in the selection of the material, in the manner in which it is handled, and in the order and form in which it is presented.

To secure the requisite unity in design, and balance in execution, it is essential that the whole subject matter should be rethought by a single individual through his own head. The more familiar alternative—the cooperative conglomerate—is at best a makeshift, and at worst an inextricable confusion. The multiplicity of points of view of a band of independent collaborating experts inevitably detracts from the homogeneous and coordinated presentation of the subject as a whole.

Such an undertaking calls neither for a pedantic arm-chair natural philosopher, nor for a mere laboratory recluse. It demands a mind steeped in wisdom rather than sodden with learning: one capable of that exact and penetrating vision of things, which no automatic application of rules of procedure can replace. Its author must be prepared to devote his whole time and undivided attention throughout a substantial portion of his working life to the realization of such a project. In return he merits the appreciative recognition of his colleagues for conferring on them a boon, the value of which is difficult to assess.

To be effective, a treatise on physics must be planned on a sufficiently comprehensive scale, and with a sufficiently broad outlook, to enable questions to be treated with their requisite amplitude, and without tiresome repetitions. A good deal of space is needed even to convey the essen-

[1] Published by Librairie Delagrave, 15 Rue Soufflot, Paris, V^e.

tials of a subject so extensive, complex and interconnected as physics. Any undue economy in explanations can only be at the expense of clarity, and is calculated to foil even a genuine attempt at understanding. It is educationally unsound to attempt, in a short course, to pick flowers from the whole field of physics. To acquire a smattering of everything is to risk systematic stultification, and to encourage the callow pose of omniscience. No cursory recital of the principles of the subject will enable a student to utilize these principles cogently in appropriate applications. A thorough mastery of a restricted, but not too restricted, portion of physics by an intensive effort provides a sounder basis for future progress than any superficial browsing over the entire field. The object of a teacher should be to foster the intelligence and initiative of his students, rather than to force them to rely on their memory, and to gargle with technical terminology. Teaching should not paralyze the student's assimilative facilities by scrap feeding, but rather consolidate his foundation studies so as to empower him to extend them as need arises. For this purpose the average text, compiled to conform to a shallow program, is inadequate. It is, from every point of view, preferable to make use of selected portions of a text having the proper depth of treatment.

It is not desirable, however, that even a comprehensive treatise should aim to include everything. It is bad policy to be completely boring, as a vain attempt to catalog every specialized type of instrument, and all variants of particular forms of apparatus, would inevitably become. The author must not emulate the squid in the promiscuous discharge of his ink sac to perpetrate typographical monuments, the embellishment of whose superstructure cannot disguise the poverty of their foundation. A very discriminating choice of what is to be admitted is imperative. Whatever is not of fundamental importance, or of real interest, must be excised, so that it is, in some respects, a safer criterion to judge an author by what he omits than by what he includes.

Upon the topics selected for discussion a proper allotment of emphasis is essential. Professor Bouasse is no anaemic purist. His work has a definite orientation towards applications. Abstract formulations are invariably led up to by concrete illustrations, and supplemented by practical examples. He holds that those parts of physics which serve no useful purpose are no more attractive, or more cultural, and are certainly less instructive than those which do; that science divorced from its applications is sterilized on its most stimulating side. If the utility and applicability of a scientific teaching affords a measure of its humanism, his treatment excels in this respect.

Professor Bouasse does, nevertheless, distinguish scrupulously between science and technology. His work is in no sense an *aide-mémoire* for the practical man, desirous only of applying formulas in a rule of thumb manner, without caring what lies behind them. It is experimental without being technical, and, while not making excursions into technology, yet does provide the prerequisites for its profitable pursuit. His aim is to treat practical problems from a scientific angle, at the same time not ignoring phenomena without actual application but possessing considerable scientific value and pedagogic importance.

The treatment must be critical throughout, all the data must be closely scrutinized and carefully checked, as far as possible by actual repetition of experimental work. This must be undertaken in no hostile spirit, but with a dispassionate fairness, to avoid any conscious or unconscious torturing of facts to force them into line with theoretical preconceptions. A genuine critic is not a carping fault finder who, though he may display the technical dexterity of a virtuoso, is productively as impotent as a eunuch. To be constructive, as well as critical, he must needs have a mature and balanced judgment. Accordingly it is, first and foremost, desirable that he should be himself an experienced investigator, and have had a suitably intimate acquaintance with physics in the making to enable him to appraise the efforts of others with the subtle insight of a connoisseur. Bouasse's own researches have covered a sufficiently wide range to render him peculiarly fitted to pronounce upon and interpret the original contributions of others. In the second place, to be authoritative, he needs to be wholly independent of vested interests. The right of frank criticism, though always conceded in theory, is comparatively rarely given effect to in practice. The com-

mitments and entanglements of favors solicited and accepted tend to stifle complete freedom of expression concerning officially sanctioned views. Bouasse has never striven after academic elevation, nor has he conspired to insinuate himself into any of the closed mutual admiration societies. When he has duly weighed and considered a topic, he has the moral stamina to uphold his conclusions, even when they happen to run counter to generally accepted tenets.

A work of the nature considered must be systematically developed, and synthetically planned; it must not degenerate into an encyclopedia. Facts must be presented in a proper logical sequence, and in their due perspective. No such necessity worries the lecturer who is content to keep one lecture ahead, since his verbal indiscretions and inconsequential ramblings are probably destined to leave no trace save in his students' notebooks. It is, however, incumbent upon a writer to pursue some coordinated scheme of exposition in a text upon which the light of a more ample publicity is destined to shine, and in which defects of style or sequence are less liable to be condoned. The ordering of ideas in a fashion at once intelligent and intelligible, is a matter of prime importance. In cases where this has become more an affair of convention than of conviction, Bouasse has not hesitated to rearrange his order of treatment to conform to a more reasonable plan.

A writer of an outstanding treatise should combine an objectivity of viewpoint, with a broad sanity of outlook. If science is to be understood properly, and applied rightly, a rational attitude with regard to it is desirable. Science is not a mystery to be venerated, but a tool to be used. Science, for the professional scientist, is primarily a means of livelihood but, in addition, it ought to provide him with a delectable pastime. It is not a subject to be discoursed upon in a hushed voice, with an impressively protracted delivery and a sacerdotal air. Nothing is better designed to strangle the effectiveness of science than to invest it with an aura of mysterious remoteness. The calculated object of semipopular metaphysical meanderings concerning the atom and the universe would appear to be to mystify rather than to enlighten. By skirting round the difficulties they delude the ingenuous reader into imagining that he grasps what he is not in a position to comprehend. This quackery, masquerading under the guise of physics, can only perform the disservice of superposing a thin veneer of conversational "science" upon a radical ignorance. Bouasse does not restrict himself to amiable and noncommittal generalities, but adopts consistently the concrete point of view which never loses sight of the physical operation behind the mathematical symbol. He rests content "with setting down in ordinary comprehensible language, devoid of eloquent phraseology, what currently passes for the most abstruse of truths, and reasoning invariably on the most commonplace of examples, reduced to their simplest terms." This somewhat nonchalant attitude is abhorrent to those who seek to set science on a pedestal, in order to preserve it from the contamination of comprehension.

It is equally important for a writer on physics to have a philosophy of his subject, and to understand clearly the nature of hypotheses, and the rôle of theories in the interpretation of facts. "To teach a science efficiently," says Bouasse, "one must have an exact idea of the true nature of theories. It is pitiful to see so much importance attached to theories envisaged, not as convenient means of grouping facts, but as representing some supposed reality. . . . " "In itself the nature of the hypotheses employed in science is indifferent, provided they are capable of precise expression in a form suitable for serving as the point of departure of an incontrovertible logical chain. A science, arrived at a certain stage in its development, cannot avoid the use of mathematics, since, once its principles have been chosen, their consequences must be extracted, an operation which a certain type of mathematics undertakes mechanically. It is essential to differentiate carefully between the logical sequence, unrolled by mathematical deduction from a clearly enunciated postulate, and the experimental series, which has to be compared, in so far as our resources allow, with each link of the logical chain, to verify whether agreement exists to some determined approximation." Bouasse adopts a mode of exposition as far as possible independent of the figurative idiom of particular, and possibly perishable, hypotheses. He never

leaves the slightest doubt as to what is postulated and what deduced, and sets down in unambiguous terms the basis of his arguments. Anything that does not appear to have any decipherable basis he ignores. He does not overwhelm us with an avalanche of erudition, couched in language so obscure as to furnish a loophole for escape either way. By omitting no links from his chain of reasoning, he is able to expunge the "it can be shown" bluff. Part of the originality of his treatment consists in making no attempt to conceal weaknesses and gloss over defects in the existing structure of physics. A sure means of advancing a science, as he observes, is to point out its imperfections, for the more obscure a question the more important is it that attention should be focussed on it.

Although possibly no one is more deeply versed in the history of physics than Professor Bouasse, he has deliberately rejected the historical method of exposition, partly because it would involve a disproportionate enlargement of an already voluminous work, but mainly because he holds that the historical presentation of a science can only be profitable for those already intimately familiar with the existing position in that science. The scientist turned historian as an afterthought more often than not cuts a sorry figure. He is liable to confuse the history of science with a biographical survey of scientists, and to subscribe to the threadbare *cliché* of a name, a date and a place. Thus he blandly ignores such major issues as the growth of germinal ideas, which decisively determine the lines of evolution of a science. Moreover, scientific historians are rarely unbiased. A racial pride and prejudice seems to foster in them the vain pretension that the majority of fundamental advances have been due to their own compatriots. No valid reason can be adduced for making a scientific text read like a school prize list. Science is impersonal, individuals disappear, or, at best, have their names retained as pegs employed conveniently to avoid circumlocution. Pseudo-historical snippets are so much mental litter tending to distract rather than entrance the student.

In a subject such as physics a settling process operates continually, and, in the course of time, much that is not founded upon sound observation, or grounded in painstaking experimentation, sinks into a merited oblivion. It is only after physics has undergone such subsidence that it provides suitable material for textbook presentation. The subject matter of a treatise should comprise the firmly established permanent acquisitions, which have given evidence of a survival value, and passed beyond the range of fickle fashion. The latest novelties of the sensational variety, with their precipitate generalizations, illegitimate extensions and untenable approximations, are not material for inclusion in a text. So many sweeping syntheses are abroad at present that the flood of paper research outstrips all possibility of experimental control. We have no infallible means of judging the mortality rate of this outpouring, beyond suspecting that it may ultimately prove to be high. At any rate it constitutes too shifting a foundation upon which to build. Physics in the process of formation should be sought in the relevant periodical literature, and not in a textbook. Resumés of recent developments are, of course, of considerable assistance. Nothing could more adequately cater for this need than the articles which appear in the *Reviews of Modern Physics*, or in the occasional contributions of Dr. K. K. Darrow in the *Bell System Technical Journal* under the title of "Some contemporary advances in physics."

Immense as has been the labor which Professor Bouasse has imposed upon himself, the result is anything but labored. He provides a fresh valuation both of familiar and of unfamiliar material characterized by the graceful ease of complete mastery. His work has been written, not to fill a program, but to give substance to the ideal of rendering accessible, to all adequately equipped inquirers, a connected survey of the whole field of established physics. It owes not a little of its singularly stimulating quality to the fact that Professor Bouasse has consulted nothing but original sources of information. He offers us no distorted version of an oft repeated, and much mangled, tale. His work provides the physicist with an indispensable work of reference, one on which he can rely for preliminary initiation into the majority of problems in classical physics and its border-line branches, and beyond which there can be only one higher authority—the original source. This monumental treatise bears so in-

delibly the imprint of the personality of its author that it constitutes far more than a source for occasional and random reference. It is a work to be read and pondered over, and its volumes should be included in the private library of every teacher of physics. With such a work available there can no longer be any valid excuse for any of us to remain in ignorance of the extent of our ignorance of our subject. A better means than that offered by Professor Bouasse of applying the necessary remedial measures could hardly be imagined.

Spectroscopy at the Massachusetts Institute of Technology

George R. Harrison, *George Eastman Research Laboratory of Physics, Massachusetts Institute of Technology*

In designing the recently completed George Eastman Research Laboratories of the Massachusetts Institute of Technology, it was desired to make adequate provision for teaching and research in spectroscopy. Careful study of the problem made it clear that on account of the large size of the grating mountings so necessary in modern spectroscopic work it would be impracticable to install equipment of the desired type in the main part of the new laboratory; it was therefore decided to construct a separate building in which the necessary freedom from temperature variations and from vibration could be obtained. This spectroscopy laboratory, which has been described in detail elsewhere,[1] has now been in operation for over a year and has entirely fulfilled the expectations of its designers. But as it was built at considerable cost, and is equipped with expensive apparatus, the question naturally has arisen as to the justification of investing funds in such a project.

There are many who feel that the golden age of spectroscopy is over, and that we cannot expect to continue to reap the harvest of stimulating discoveries to which it led during the two decades following 1913, when such great generalizations as Pauli's exclusion principle and Heisenberg's uncertainty relation proceeded directly or indirectly from use of the spectroscope. Certainly the main attention of theoretical physicists, who have learned, like the gulls, that the greatest return for each nourishment-seeking plunge is to be found at the crest of the main wave, is turning now from the outside of the atom to its inner nucleus. Can it be that the tide of physical conquest is rolling on, leaving the puttering and myopic spectroscopist happily fitting the pieces of his jigsaw puzzle into a pattern, which even when complete, will be unfruitful?

Three lines of evidence exist which indicate that so discouraging a picture is incorrect. In the first place, the main work which spectroscopy started out to do, in elucidating the structure of the atom, has scarcely been begun. We have found out how to do the job, but less than one percent of the actual work has been completed. Secondly, certain new fields such as the chemistry of excited atoms and the metallurgy of complex alloys are just being thrown open and must rely almost entirely on spectroscopic data for their theoretical advancement. Finally, it is becoming evident that the spectroscope, long known to be the most powerful tool available to pure science, can be of use also in attacking technological and industrial problems which have hitherto defied solution.

The routine measurement of wave-lengths and the classification of spectrum lines is not to be considered of interest only to the spectroscopist, for many physical phenomena such as critical potentials and magnetic susceptibilities require spectroscopic data for their interpretation. The astrophysicist relies almost entirely on the product of the spectroscope for his raw material, and I have yet to meet an astrophysicist who was not chafing at the lack of properly classified spectra or accurate line intensities which he needed to aid his researches. Our quantitative knowledge of the extranuclear structure of the atom may be considered as reasonably complete for one atom—hydrogen. As for the remaining ninety-odd, we have a number of qualitative ideas, but in very few cases have we the exact knowledge required to explain such things as chemical bonding in detail. The whole modern science of theoretical

[1] K. T. Compton, Physics **2**, 205 (1932).

chemistry is largely based on spectroscopic data, and actually faces handicap because of the paucity of such data; this fact is little realized because it is obscured by the still greater difficulties involved in the clumsy and complicated methods of calculation now needed to solve problems in theoretical chemistry.

Granting, then, that routine spectroscopic measurements should be continued for the benefit of many branches of natural science, what remains to be done? There is every reason to believe that more spectrum lines remain to be discovered than have hitherto been observed, since each stage of ionization of an atom produces a new set of lines. Of the lines which have already been found, wave-lengths of less than twenty percent are known to the required accuracy. Probably less than ten percent of the known atomic spectrum lines have been classified in accordance with the energy levels from which they originate, while in the corresponding molecular case these figures must be divided by ten. A vast region of the spectrum, covering a range in which two hundred times as many spectrum lines as occur in the visible are expected to fall, is not even properly equipped with wave-length standards as yet! When one wants to know the relative intensities of spectrum lines he usually either goes without the information or makes a rough estimate. Technical problems still confront the experimenter; will anyone ever be able to rule a concave grating much better than those made by Rowland almost fifty years ago?

Now come industrialists eager to pour forth at gatherings of their fellows testimonials to the wonders of spectroscopic analysis; deep secrets of competitors laid bare, whose silvery raincoat materials the spectroscope shows owe their sheen to bismuth, or whose radiator cap ornaments owed their failure to buckle to the absence of magnesium. Manufacturers of spectroscopic equipment, eager to tap this new field, design simplified apparatus capable of giving complicated analyses when used by "any intelligent lad." Mining engineers, textile manufacturers, wire companies, agricultural experts, biologists, criminologists, automobile manufacturers, oil and gasoline refiners, and technologists without number are learning of the usefulness and availability of this newly applied tool to their businesses and are anxious to know more about it.

Accordingly, the Institute has recognized its duty and its privilege, to support research in pure and applied spectroscopy as being basic to many sciences and hence to all technology, to train young men for science and industry in this field, and to cooperate directly with industrial organizations in attacking special problems; for these reasons it has seen fit to undertake the program in spectroscopy which is here described.

In outlining a course of study to be followed by students who intend to make spectroscopy their life work we have followed the rule that thorough training in fundamentals is of more importance than consideration of technical details. For this reason the same course of study is taken by students who intend to go into teaching and to continue scientific research, and those who intend to become industrial spectroscopists. All students in the physics department are required to take during their junior year a lecture and laboratory course in *Structures of Atoms and Molecules*, where they make their first intimate contact with spectroscopy, and most of them elect courses in *Line Spectra* and *Excitation of Spectra* during their senior or first graduate years. Those most interested in the field under discussion then continue with a course on *Theory of Spectra* and register continuously for the *Spectroscopy Seminar*. Their laboratory experience is taken care of by a course on *Special Topics in Spectroscopy* and by registration for research for the bachelor's, master's, or doctor's thesis.

Recently summer courses have been introduced for the benefit of students in other departments desiring to use spectroscopy in their own fields, and for industrialists. These, entitled *Practical Spectroscopy* and *Quantitative Spectroscopic Analysis*, are supplemented by laboratory work in *Applied Spectroscopy*. The response to these courses has been very satisfactory, and they will be continued.

During the past summer the spectroscopy laboratory was thrown open to properly qualified research workers from other institutions who desired to do summer work, and a number spent portions of the summer carrying on their investigations in it. Advantage was taken of their presence to hold a summer spectroscopic conference,

which was attended by about 120 scientific and industrial spectroscopists, including a number from England and from Canada. Daily sessions were held for a week, and the continuous attendance of the conference members and the interest shown in the discussions indicated more surely than any argument that spectroscopy is a growing rather than a decaying science.

The equipment of the spectroscopy laboratory has been chosen, first so as to be flexible and to lend itself to almost any spectroscopic problem which might need investigation, and second to be especially adapted to certain types of research which now present themselves. Fields which are now receiving special emphasis include wave-length measurements in atomic and molecular spectra, extreme ultraviolet vacuum spectroscopy, intensity measurements in line and band spectra, hyperfine structures of spectrum lines, analysis of complex spectra, and quantitative spectroscopic analysis of materials.

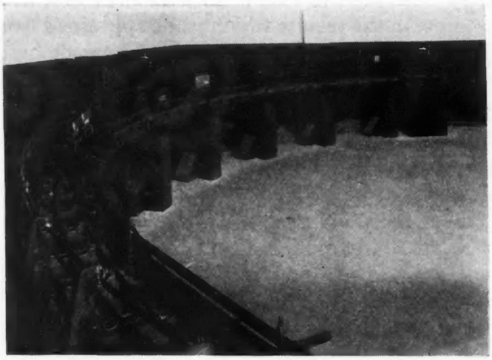

FIG. 1. A portion of the 34-ft. circle, showing the wave-length and intensity measuring tracks, and several cassettes.

Most of the grating wave-length measurements made in the past have been carried out by means of concave gratings of 21-ft. radius, ruled with about 90,000 lines spaced 15,000 to the inch, the familiar "grosse gitter des Institutes" of the literature. R. W. Wood, using Rowland's engines, has recently succeeded in ruling very good gratings with as many as 180,000 lines spaced 30,000 to the inch. The Institute possesses several gratings ruled in this way, the most notable being one having a radius of curvature of 34 ft. This has been fixed in a modified Paschen mounting, a view of a portion of which is shown in Fig. 1, and gives unsurpassed dispersion and resolving power. Fourth-order lines can be photographed in certain regions of the spectrum, giving a dispersion, fully utilized, equivalent to the twelfth order of the gratings until recently considered standard. In Fig. 2 is shown a small portion of the arc spectrum of iridium with its accompanying iron standard spectrum, as photographed with this grating. This and a companion grating having half as many lines per inch can be used at all wave-lengths between 10,000 and 2000A and are fitted up with special slits, cassettes, and tracks, so that they can be used to best advantage for wave-length measurements, intensity measurements, and hyperfine structure determinations.

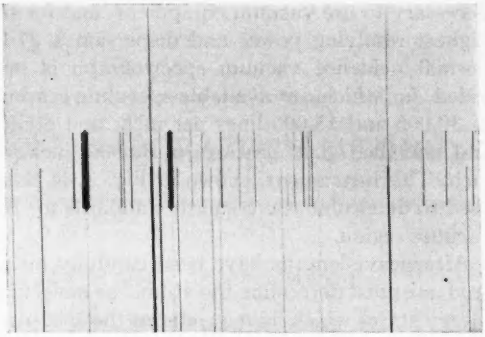

FIG. 2. A small section of the spectrum of iridium as photographed with the 34-ft. 180,000-line grating. The short lines are the iron comparison standards. The complete set of spectrograms photographed in this pair of exposures is over forty feet long.

At wave-lengths shorter than 2000A it is

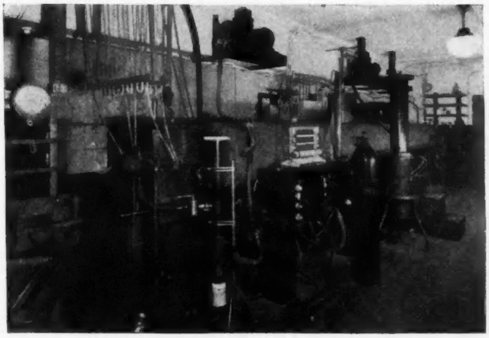

FIG. 3. A 21-ft. vacuum spectrograph for the extreme ultraviolet region.

necessary to use vacuum equipment, and for the highest resolving power and dispersion a 21-ft. normal-incidence vacuum spectrograph is provided, for which are available speculum gratings of 30,000 and 15,000 lines per inch, and etched and unetched glass gratings of 30,000 lines per inch. This instrument, shown in Fig. 3, is being used to determine wave-length standards for the vacuum region.

After wave-lengths have been carefully measured one must determine the atomic or molecular energy states which have produced the spectrum lines, by analyzing the spectra. To speed this process the Institute has developed a mechanical interval analyzer which has shown itself to be a great labor saver, and in fact makes possible the analysis of spectra which the mere magnitude of the effort required had previously made almost impossible. For this purpose one must also study the behavior of the various lines under different experimental conditions, and a number of smaller spectrographs, including normal and grazing-incidence vacuum outfits, are available for this purpose.

One of the most interesting recent developments in the spectroscopic field has been the determination of the spin moments of the nuclei of atoms by means of a study of the fine structures of the lines they emit. This usually requires the highest resolving power available, and to supplement the large gratings one must turn to interferometric apparatus. The laboratory possesses an excellent selection of quartz Lummer-Gehrke plates, Fabry-Perot etalons, a Gehrke-Lau multiplex interference spectroscope, and a Hilger fused-quartz reflection echelon which can be used in the vacuum region. Each piece of spectroscopic equipment is so arranged that intensity measurements can be made as a routine part of its use wherever this is possible.

While every precaution is taken to protect this equipment from improper handling, undergraduate students are allowed to use it as soon as they demonstrate their ability to do so and their interest in the results which can be obtained from its use. An enthusiastic group of investigators, working in close cooperation, is giving life to the laboratory and is helping to make what is hoped will be a useful and effective center of spectroscopic teaching and research.

APPARATUS, DEMONSTRATIONS AND LABORATORY METHODS

An Improved Apparatus for the Study of the Concave Mirror

J. G. Moorhead, *Department of Physics, Westminster College, New Wilmington, Pennsylvania*

After using for several years improvised apparatus for the experiment on the concave mirror in the general laboratory, the following apparatus was devised. With makeshift apparatus, errors of several millimeters are almost unavoidable in measuring the object and image distances. With this apparatus, the distances can be measured with an error of a millimeter or less, which is of the same order of magnitude as the uncertainties arising in focussing an image under the most favorable circumstances.

Fig. 1 shows the general plan of the apparatus. A meter stick is mounted flat on a board about 12 cm wide and about 110 cm long. A concave mirror of diameter 7.5 cm and focal length about 17

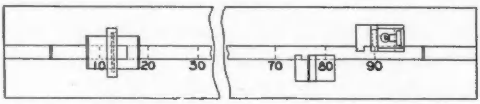

Fig. 1. General plan of concave-mirror apparatus.

cm, is mounted in a support which is grooved to slide along the meter stick. As shown in Fig. 2a, the upright piece is bevelled back so that the edge indicates on the meter stick the position of the back of the mirror. It is necessary to use a mirror of good quality as the cheaper ones do not give clear images. Fig. 2b shows the lamp box and support, the latter being grooved to slide along the meter stick on one side of the axis. The lamp, a flashlight bulb, is connected by a flexible cord to a storage battery. A hole is cut in the box, and a ground glass is set in flush with the surface, over the hole. A piece of wire netting is placed over this hole to serve as an "object" and a small hole punched in this netting serves as a reference mark. The position of the object with respect to the meter stick is indicated by the intersection of the perpendicular piece with the meter stick. The support for the screen, shown in Fig. 2c, is grooved to slide along on the other side of the meter stick. Its vertical surface carries a card about 13 by 8 cm. The position of this screen is indicated by the intersection of the vertical piece

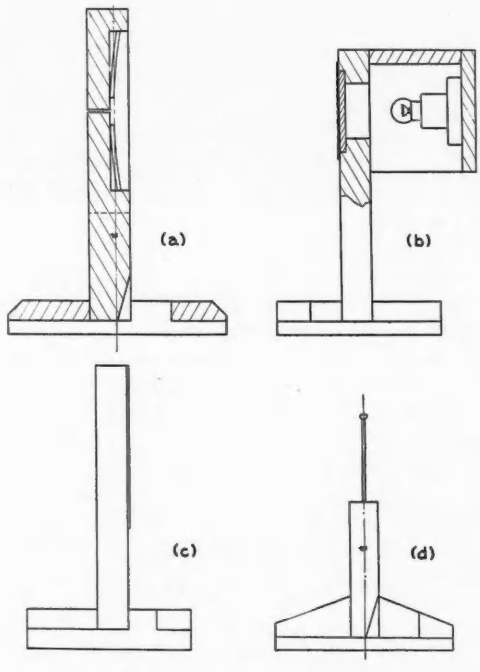

Fig. 2. Diagrams showing, in cross section, (a) the mirror support, (b) the lamp box and its support, (c) the screen support, and (d) the support for the nail.

with the meter stick. Another support, Fig. 2d, carries a nail for locating the image by the parallax method. The bevelled edge gives the position of the nail on the meter stick.

The object piece can be set at any position along the meter stick, the corresponding image focussed on the screen, and the distances read off quickly on the meter stick. Since the object and screen supports are on opposite sides of the meter stick, they can pass each other, thus allowing easy adjustment of the object distance through a wide range of values, provided that the focal length of the mirror is sufficiently short. The lamp box is only 5 cm wide, and is set as near the optic axis as possible; consequently the image is formed on the screen even when almost a meter from the mirror. The images can be located by the parallax method for all positions of the object. In locating virtual images, the nail support is placed behind the mirror.

A Simple Experiment on Forced Vibration

I. WALERSTEIN, *Department of Physics, Purdue University*

THE following simple apparatus for demonstrating resonance in mechanically vibrating systems can also be used to show the reaction of the resonating part back on the driving mechanism.

A d.c. motor whose speed can be regulated by the input current is fastened to the middle of a pine board about 9 ft. long, 5.5 in. wide and 3/4 in. thick. The ends of the board are placed on two tables between two tracks to prevent side slipping during vibrations. This essentially forms a vibrating system fixed at the two ends and free to vibrate in the center in a vertical direction. The motor is provided with an eccentric which consists essentially of an iron cylinder 3 in. long and 1/2 in. in diameter, which is attached near one end to the shaft of the motor. As the motor rotates, this cylinder imparts a periodic impulse to the board. As the current through the motor increases and the period of rotation reaches a value equal to the natural period of vibration of the board, the usual phenomenon of resonance sets in, and the supporting board vibrates with considerable amplitude. This is attained with a current of 0.14 amp. and the period is 1/3 sec.*

As the current through the motor is now further increased, the speed of rotation of the motor no longer mounts, but remains that which was imposed on it by the vibrating board which retains its natural period of 1/3 sec. The current could be increased to 0.19 amp. or more, if done gradually, without changing the speed of the motor.

If the vibration of the board is now stopped, by seizing it in the middle, the motor will immediately speed up to about 300 r.p.m. and the ammeter in series with the motor registers 0.17 amp. *This extreme difference in speed of rotation is very striking for class demonstration, as is also the drop in current when the motor gains speed.*

The apparatus described may be considerably modified and the dimensions changed to suit the type of motor available. Aside from the application to mechanically vibrating systems, it may well be used as an introductory experiment to illustrate the principle of the constant-frequency crystal oscillator where the oscillator tube corresponds to the motor, and the crystal to the vibrating board in the foregoing experiment.

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* Up to this point the experiment is well known in a variety of forms.

An Experiment on the Ellipsoid of Inertia

M. H. Trytten, *Department of Physics, University of Pittsburgh*

As a usual thing, laboratory courses in intermediate mechanics stress experiments whose main object is to give experience with instruments of precision. In the course which the writer has conducted, an attempt was made to devise experiments of a more illustrative type. In particular, the apparatus described below was designed to measure the moments of inertia of a body about various centroidal axes as well as about axes through points outside the center of mass. From such a study the ellipsoid of inertia and its inverse ellipsoid may be plotted as a function of space coordinates.

The author has found that very few students have the ability readily to visualize the ellipsoid of inertia, and, in particular, they seem to have considerable trouble in following its changes in shape as one shifts the point through which the axes of rotation are drawn. This is unfortunate, for the momental ellipsoid is the most common of the tensor ellipsoids and any experience gained with it is of value in visualizing other tensor quantities.

The apparatus may be understood by a glance at Fig. 1. A circular aluminum plate is mounted rigidly at right angles to a vertical steel rod. The steel rod rides in a fine conical bearing at the bottom and is held at the top by a special low-friction roller bearing. A heavy coil spring is attached to the supporting frame at the outside and to the rod at the inside. It furnishes the restoring torque for oscillation. The upright rods may be fastened at various places by means of screws through holes in the circular plate. The body to be investigated has holes in it at right angles to each other and through the center of mass. A rod passing through these holes is clamped in place horizontally between the uprights by set screws.

In practice the body is first mounted with its center of mass immediately on the axis of rotation of the system. The orientation of the body may be measured by a device such as the one shown in Fig. 1. The period is observed. The body is then turned through a known angle and the period again observed. As this process is repeated, a set of values is obtained of the period as a function of the angle. The apparatus is next calibrated by placing on it at various known distances from the axis a mass whose moment of inertia may be readily calculated.

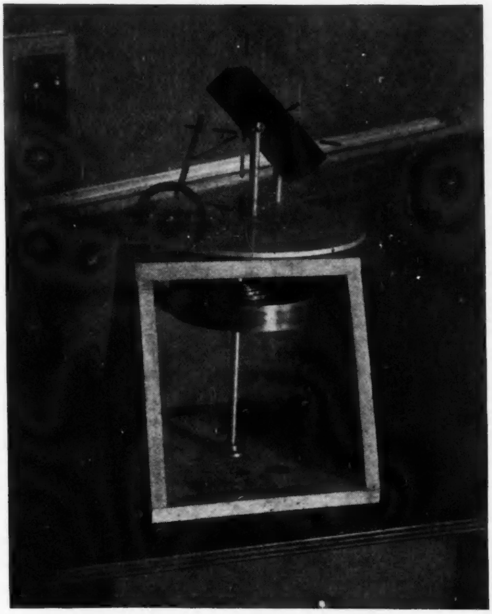


Fig. 1. Moment of inertia apparatus showing body mounted. The body is of oak unsymmetrically loaded with lead. An instrument for measuring orientation is shown. The dotted lines show the axes about which the moment of inertia is measured.

One can, of course, find the torsion constant of the spring. But a calibration curve of moments of inertia of the added load *versus* period is more satisfactory since it obviates a consideration of damping, etc.

In this way one arrives at the moment of inertia as a function of the angle. The reciprocal of the radius of gyration plotted as a function of the angle should yield an ellipse. The body is now mounted with the horizontal support rod through a second hole passing through the centroid at right angles to the first, and a new set of values taken about a series of axes. A second ellipse can be plotted. The two ellipses now plotted are

sections of the momental ellipsoid made by planes at right angles to each other. In practice it is probably desirable to place the holes in the body so that the ellipses represent sections made by planes passing through two principal axes of the momental ellipsoid. Fig. 2 shows a class-room model of the ellipsoids of inertia for the body shown mounted in Fig. 1.

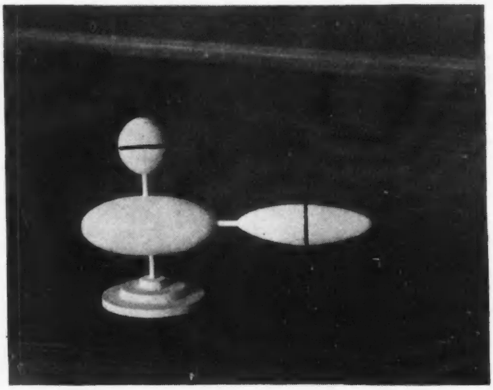


FIG. 2. Ellipsoids of inertia, in class-room models, for the body mounted in Fig. 1. The largest is the centroidal ellipsoid. The other two are for axes through a point one inch from the axis of the apparatus in the directions shown. The fine lines represent the measured ellipses. The other major axis does not change.

By mounting the supporting uprights in such a way that the center of mass is now away from the axis, as shown in Fig. 1, the moment of inertia may be obtained about axes not through the center of mass. By rotating the body as before, a series of values is obtained yielding a new ellipse. This ellipse is one represented by the fine line in Fig. 2. Since the moment of inertia in the third direction does not change (the lengths of the ellipsoids shown in Fig. 2 do not change along the line joining them), sufficient data are at hand to plot this new ellipsoid.

By mounting the body again through the second hole through the centroid, a second ellipse may be plotted represented by another fine line on the third model of Fig. 2. As before, the ellipsoid may now be plotted. It is perhaps well to state that for the body used it was only necessary to displace the center of mass one inch from the axis of rotation to achieve the change in shape and size represented in Fig. 2. The models, of course, had to be mounted farther apart to prevent overlapping.

The apparatus was built in final form, the measurements made and the models constructed by one of the students in the class, Mr. H. R. Montague. The author wishes to express appreciation of his industry, interest and ability.

The Magnetic Force-Finder

LUDVIG C. LARSON, *Department of Electrical Engineering, University of Wisconsin*

THE *magnetic force-finder* is an instrument for measuring the force exerted by a magnetic field upon a straight length of current-carrying conductor suspended in the field. Since the value of the magnetic flux density at a point may be defined as equal to the force exerted per unit of length upon a straight conductor carrying unit current and suspended at right angles to the direction of the flux-density vectors, the force-finder serves as an instrument for measuring the value of the magnetic flux density in the region of the suspended conductor. This article describes a laboratory apparatus consisting of a force-finder provided with auxiliary field coils of known dimensions for the purpose of setting up magnetic fields. By means of the apparatus, the student may obtain an experimental check of the law of force between conductors and of Ampere's formula for computing the magnetic flux densities. He may also experimentally determine (to within ± 2 percent) the value of the proportionality constant μ (termed the permeability of space) which enters into Ampere's formula. The apparatus can also be used to demonstrate the force upon a current-carrying conductor even though it is necessary to omit or defer the check computations.

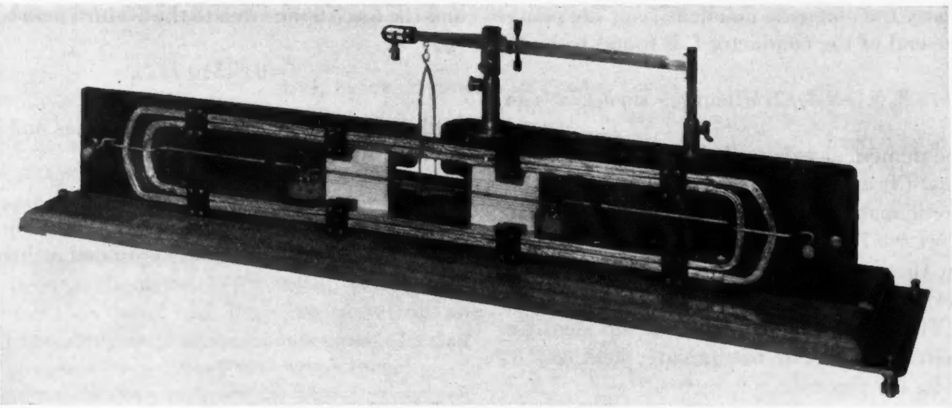


FIG. 1. View of the magnetic force-finder.

Fig. 1 shows that the force-finder consists of two rectangular field coils and a current-carrying conductor suspended midway within the auxiliary field coils by means of a beam balance. The field coils, differing in dimensions and number of turns, may be used singly or in series. Mercury serves to convey the current to and from the suspended conductor. The buoyant effect of the mercury is the same at all times since the beam is balanced at the same level before readings are taken as well as when the downward magnetic force is being measured. The dragging effect of any oxide film forming upon the surface of the mercury can be minimized through the use of clean mercury covered with a very thin layer of thin oil. The tips of the suspended copper conductor are chromium plated. Fig. 2 shows the most important dimensions of the equipment.

The magnetic force upon a current-carrying conductor may be computed as follows. Ampere's formula has the form

$$dB=\frac{\mu I \sin (r, l)\, dl}{4\pi r^2},$$

in the weber ampere-turn centimeter system of units.[1] Thus, referring to Fig. 3, the magnetic flux density at point o due to I_f amperes flowing in the inner field coil is

$$B_o=(\mu N_1 I_f 4/4\pi)\int_o^{\theta_1} \sin (r, l)\, dl/r^2, \quad (1)$$

[1] See, for example, Bennett and Crothers, *Introductory Electrodynamics for Engineers*, Secs. 241–243, 246a.

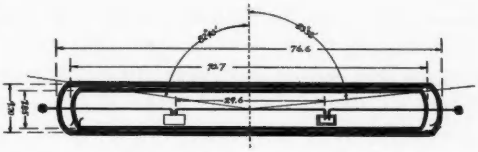


FIG. 2. Principal dimensions of parts, in centimeters. The inner field coil, N_1, has 4 layers, 48 turns, No. 16 B and S gauge G. E. Co. "Deltabeston" copper wire and the outer coil, N_2, has 5 layers, 60 turns. The force rod in the center is made of No. 8 copper wire.

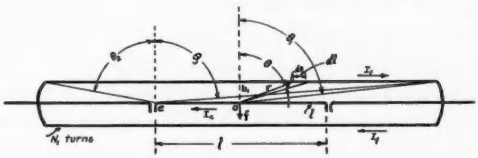


FIG. 3. Schematic diagram showing subtended parts of inner field coil, relative directions of field and conductor currents, and direction of magnetic force upon conductor l.

where B_o is in webers per cm^2, μ represents the permeability, N_1 represents the number of turns of wire composing the inner field coil, I_f represents the field-coil current, in amperes, and (r, l) is the angle between the short length of field coil (dl) and the line r to the point o. Since, in Fig. 3, $\sin (r, l)dl=rd\theta$ and $r=b_1/\cos\theta$, Eq. (1) may be written

$$B_o=(\mu N_1 I_f/\pi)\int_o^{\theta_1} \cos\theta d\theta/b_1 \quad (2)$$

or

$$B_o=\mu N_1 I_f \sin\theta_1/\pi b_1. \quad (3)$$

Similarly the magnetic flux density at the point e at one end of the conductor l, is found to be

$$B_e=(\mu N_1 I_f/2\pi b_1)(\sin\theta_3-\sin\theta_2). \quad (4)$$

The numerical values of the factors appearing in Eqs. (3) and (4) are: $\mu=0.4\ \pi 10^{-8}$ (for nonmagnetic materials),[1] $N_1=48$ turns, $b_1=3.93$ cm, $\sin\theta_1=0.9937$, $\sin\theta_2=-0.9816$, $\sin\theta_3=0.9969$. When these values are substituted in Eqs. (3) and (4), B_o and B_e are found to differ by 0.6 percent. The mean value is used. The flux densities at points o and e due to the outer field coil N_2 differ by 0.5 percent.

Eqs. (3) and (4) neglect the contributions to the magnetic flux density at points o and e due to the curved end-parts of the field coils. Computations show that the average increase in flux density due to the ends (assumed to be arcs of circles) is 1.68 percent for the inner field coil and 2.05 percent due to the outer field coil.

The magnetic force upon a straight conductor carrying a steady current and placed in a uniform magnetic field is

$$f(\text{dyne-sevens})=BI_c l\sin(B, l), \quad (5)$$

where B represents the flux density of the field measured in webers per square centimeter, I_c represents the steady current flowing in the conductor, l now represents the length of the conductor in centimeters, and (B, l) represents the angle between the B-vector and conductor l. Since $l=29.6$ cm and $\sin(B, l)=1$, then from Eqs. (3) and (4) (together with the additions due to the effect of the curved ends of the field coils), and from Eq. (5) the force *in grams* upon conductor l due to the inner field coil is

$$f=0.01489\ I_f I_c, \quad (6)$$

and the force upon l due to the 60-turn field coil is

$$f=0.01510\ I_f' I_c. \quad (7)$$

With both field coils connected in series and aiding each other,

$$f=0.03000\ I_f I_c. \quad (8)$$

Table I lists measured and computed values of these forces.

TABLE I. *Measured and computed values of magnetic forces exerted upon current-carrying conductor.*

N field turns	I_f Amp.	I_c Amp.	Force g obs.	Force g comp.	Ratio of computed to measured force
48	9.20	9.20	1.24	1.26	1.015
48	12.06	12.06	2.14	2.16	1.010
48	14.60	14.60	3.13	3.18	1.015
48	18.90	18.90	5.30	5.32	1.005
60	8.70	8.70	1.17	1.14	0.975
60	11.20	11.20	1.92	1.89	0.984
60	17.50	17.50	4.58	4.62	1.006
108	9.90	9.90	3.00	2.94	0.980
108	11.75	11.75	4.16	4.14	0.996
108	14.20	14.20	5.93	6.04	1.018

The force upon the current-carrying conductor due to the earth's field is generally less than 1 percent of the total measured force. Either direct or alternating current may be used in the force-finder. When alternating current is used, the field coil or coils should be connected in series with the suspended conductor. The reactance of the field coils is not sufficient to be taken into account if the frequency of the supply is not greater than 60 cycles per second.

An Apparatus for the Electrolysis and Synthesis of Water and the Photosynthesis of HCl

J. G. BLACK, *Morehead State Teachers College*

THE experiment on the electrolysis of water may be made more interesting by mixing the same gases which result from the electrolysis and exploding them to reform the water, but no rugged, convenient apparatus for this experiment has been available with the result that only a few lecturers have had the time to set up an improvised arrangement for the purpose and the students have missed the experiment.

The arrangement shown in Fig. 1 is rugged and the results obtained with it are certain. Gases from the Hofmann apparatus are allowed to rise through the water in the tube at the top and there displace the water and force it into the bulb at the left. A spark from a small induction coil is then passed between the spark connections and the resulting explosion blows the stopper out of the top of the apparatus. This arouses considerable interest from the students.

If the chlorine generator shown at the right in Fig. 1 is inserted at the rubber tubing connection and chlorine gas is allowed to mix with the hydrogen it is easy to show the photosynthesis of HCl. When light from the sun or from a carbon arc is focussed on the mixed gases an explosion results and HCl is formed.

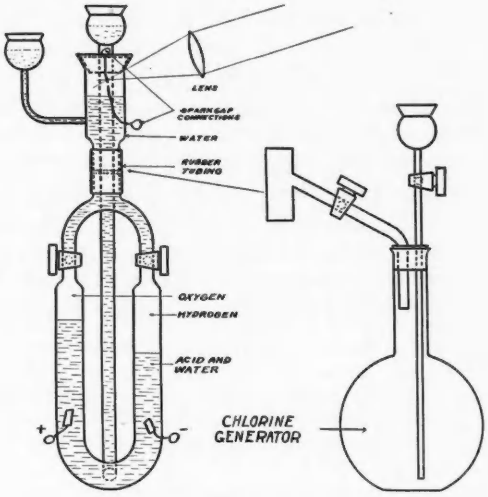


FIG. 1. Apparatus for the electrolysis and synthesis of water and the photosynthesis of HCl.

Neon Lamps for Electrical Measurements and Demonstrations

D. S. AINSLIE, *McLennan Physical Laboratory, University of Toronto*

THIS paper outlines three methods of employing neon test lamps for electrical demonstrations and measurements that ordinarily are made with much more complicated apparatus.

A neon lamp can be used to demonstrate some of the principles involved in the operation of an induction coil. The lamp is connected to the secondary-coil terminals of a small induction coil while a mercury press key and battery are connected in series with the primary coil. With the automatic make-and-break short-circuited and with a suitable value of the e.m.f. in the primary circuit, the neon lamp flashes momentarily when the primary circuit is broken but shows no response when it is made. If an old-type Ford ignition coil is employed, one dry cell is sufficient for the primary circuit. This provides an excellent lecture demonstration for showing that the e.m.f. is greater on the break than on the make. If the experiment is modified by closing the press key and using the automatic make-and-break in the primary circuit, only one terminal of the neon lamp glows, thus indicating the unidirectional character of the secondary e.m.f.

Two interesting alternating-current tests can be carried out by means of a neon lamp. In the first test, designed to show the relation between maximum and effective voltage values, a slide-wire resistance is connected across the source of the e.m.f., and the lamp and an a.c. voltmeter are connected in parallel to one end of the resistance and of the slider respectively. The voltage applied to the lamp is gradually increased by means of this simple potentiometer arrangement until the lamp lights up, and the voltmeter reading corresponding to this point is noted. The neon lamp is next connected to a variable d.c. source and a measurement is made of the minimum voltage required for a discharge through the lamp. This value corresponds to the maximum for the r.m.s. value of the a.c. voltage registered by the voltmeter in the first measurement.

The following average values were obtained in an experiment of this type: a.c. voltage required to start the discharge, 88.5; minimum d.c. voltage required to start the discharge, 125. Hence the ratio of maximum and r.m.s. values for the a.c. circuit is 125/88.5, or 1.41.

The second test employs the neon lamp in conjunction with a friction-drive rotating mirror to make an accurate determination of the frequency for an a.c. circuit. The speed of the rotating mirror is adjusted until the images of the lamp, seen in the mirror, appear to be stationary. The frequency of the a.c. source is then some multiple of the speed of rotation of the mirror. In a test of this nature made with a 60-cycle rotary converter, the foregoing condition was fulfilled for a speed of rotation of 385 revolutions per minute of a four-sided mirror. This speed corresponds to 6.41 revolutions per second. Other work showed that the machine was running above normal speed. Hence the frequency was 64.1 cycles per second.

Teaching Aids

Motion Pictures

The Eyes of Science. 3 reels, silent, 45 min. running time, either 16 or 35 mm (the latter in color). Bausch and Lomb Optical Company, Rochester, N. Y. Loaned free of charge.

An industrial film of a very high order which deals with the theory, manufacture and application of scientific optical instruments. Among the unique scenes recorded are the manufacture of lenses, the passage of light rays through prisms and lenses, Newton's rings, and strains in a structure revealed by polarized light. The photography is exceptionally fine. Reservations for the film should be made about three weeks in advance.

Out of the Silence. 1 reel, sound-on-film, 35 mm. Western Electric Co., Public Relations Department, 120 W. 41st St., New York, N. Y. Loaned free of charge.

A dramatized presentation of the use of the ear aids developed in the Bell Telephone Laboratories. Includes animated drawings of the human organs of hearing.

The Voice That Science Made. 1 reel, sound-on-film, 10 min. running time, 35 mm. Western Electric Co., Public Relations Department, 120 W. 41st St., New York, N. Y. Loaned free of charge.

The action of the human vocal organs is contrasted with the artificial larynx which has been developed in the Bell Telephone Laboratories.

New X-Ray Machine. 1 reel, silent, 16 mm. Powers X-Ray Products, Inc., 205 West 39th St., New York, N. Y. Loaned free of charge.

Shows x-ray apparatus in operation.

Charts

The Eye and How We See. 8 charts, in colors, each 20×26 in. The Better Vision Institute, 205 East 42nd St., New York, N. Y.

More than 40 diagrams which show the structure of the eye, action of lenses, the prismatic spectrum, eye defects, vision tests, etc.

Tests

Comprehensive Examinations. The University of Chicago Board of Examinations. Pp. 200. Planographed edition, paper cover. University of Chicago Book Store, Chicago, 1932. Price $0.65.

Examinations in Physical Sciences. The University of Chicago Board of Examinations. Pp. 104. Planographed edition, paper cover. University of Chicago Book Store, Chicago, 1932. Price $0.50.

The comprehensive examinations were given in June, 1932 and cover the four introductory courses in the biological, physical and social sciences, and the humanities. The examinations in the physical sciences are five in number and were given in September and December, 1932. Most of the tests are of the short-answer type.

DISCUSSION AND CORRESPONDENCE

On the Relation Between Magnetization Curves and Hysteresis Loops

IN textbooks of physics and electrical engineering, there often appears a figure showing a combined hysteresis loop and magnetization curve. Usually the author draws his own curves to look as he thinks they should without reference to actual experimental results, in spite of the fact that many thousands of sets of such data have been obtained. As a consequence the magnetization curve is often shown approximately halfway between the ascending and descending halves of the hysteresis loop. This is incorrect, since actually the normal induction curve at the upper part follows the ascending branch of the hysteresis loop very closely, and for soft magnetic materials particularly, often lies slightly outside of the loop for a considerable distance.

Two generations ago, Ewing showed this effect in one of the figures in his classical book on magnetism. He made no comment, however, on the effect. Magnetization curves and hysteresis loops have since appeared plotted correctly in a few textbooks written by experts who have used actual experimental data. It is not uncommon, and particularly unfortunate, to see these curves presented incorrectly in books dealing with laboratory experiments in electricity and magnetism.

We urge that in presenting curves in textbooks, even for theoretical discussion only, they be based, if possible, on actual experimental data. Such presentation tends to give the student greater confidence in the author.

There is another, similar, error which sometimes appears in articles and books on radio. Audiofrequency transformers often carry in the primary a considerable d.c. component of current on which is superposed a small a.c. ripple. This results in a small hysteresis loop in the transformer core displaced a considerable distance up on the normal induction curve. In discussing the magnetic effects the author often shows this minor loop with its center on the magnetization curve with one tip to the right and the other to the left of the curve. This is impossible, except under very special conditions which do not ordinarily arise. The upper right-hand tip of the loop should lie on the normal induction curve with the whole loop at the left. Such an error could be made only by writers who have not actually obtained such data and plotted the results.

Thomas Spooner
Research Laboratories
Westinghouse Electric and Manufacturing Company

Acoustics for Students of Music

I GREATLY enjoyed reading Professor Stewart's stimulating and provocative article published in the September number, entitled: "Heresy Concerning Specialized Physics Courses." I should like to outline some of my own experiences along similar lines, and to comment briefly upon the controversial question which arises.

In 1920, while a student at the Army Music School, in New York, I was subjected to a "course" in acoustics which was conducted by the catechism method. The teacher, who was a superbly competent martinet of the old school of thought, had prepared a list of 100 questions and answers; and he expected the answers verbatim! Having taught physics before joining the Army, I felt sure there was something wrong! Yet it seemed to me that the science of acoustics had a place in the education of professional musicians. A little later I asked Doctor Frank Damrosch of the Institute of Musical Art whether he thought so too. He replied that he did; but that the time was hardly ripe for the introduction of the subject, at least as it was usually taught.

Ten years later, the physics department of the Carnegie Institute of Technology was asked by the music department of the same institution to plan a course in acoustics for candidates for the master's degree in music. As Professor Stewart points out in his article, no prerequisite in physics and little in mathematics can be assumed. Yet it seemed clear that many highly interesting topics in acoustics would have to be left out if arithmetic and elementary algebra were to be ignored by the lecturer. Accordingly, a course was given in the summer school, and with the aid of the experience thus gained, the following catalog outline was prepared:

Acoustics of Music. Lectures and experimental demonstrations in those parts of the science of acoustics which are of special interest to musicians. Among the topics treated are sound waves, simple harmonic motion, noise and tone; characteristics of tones; methods of recording sound waves; harmonic analysis; the mechanism of hearing; tone-qualities of musical instruments, phonographs, and radio receivers; diatonic and chromatic scales; just intonation and equal temperament; acoustical principles involved in the construction of orchestral, band, and keyboard instruments; characteristics of speech-sounds; architectural acoustics.

My course is now offered as an elective for graduate students in music. I infer from Professor Stewart's statement, "It is presented without laboratory and lectures," that he too employs an informal "conference" method in class. This would seem feasible only with groups of fewer than twenty students. In establishing pleasant relations with the group it is a great help to the teacher if he has had professional experience in music. An extensive use of demonstration equipment seems desirable. Two experiments that have aroused considerable interest are the projection of wave forms with the aid of an oscillograph and the rating of an electric tuning-fork by a stroboscopic method.

I have not hesitated to employ arithmetic and elementary algebra in the treatment of certain topics. I do not see how the subjects of wave-length, Doppler's principle, the harmonic series, and the details of construction of musical instruments, can be developed without their assistance; and indeed our students have been gracious in their acceptance of such presentation. I cannot accept the implication that music students are dullards in arithmetic, and impatient with its application. In fact, the evidence has been quite the other way! It is true that much of the science of acoustics can be treated nonmathematically; but is it not equally true that any physical science consists largely in the application of arithmetic to the physical situation? How, for example, can the difference between just intonation and equal temperament be adequately explained without recourse to calculation? Or, to take a simpler instance, if the lecturer is not allowed to multiply by 2, 3, 4, etc., how can he show the true nature of the harmonics produced by a string or a pipe? I do not contend that such topics should be emphasized, to the comparative neglect of others; indeed, I think they should be included with caution, and never more than one in a period; but I do feel that they exhibit the true nature of the science, and show the essentially noncontroversial and evidential methods by which the scientist attacks his problems.

I heartily agree with Professor Stewart that "departments of physics should . . . teach a needed specialized course in physics to meet the desires of any college or department." I believe further that they should regard such a course as a heaven-sent opportunity to present the scientific method in action. This has the highest cultural value for persons studying the fine arts. If culture means anything, it means an appreciation of the true nature of professional activities remote from those in which the student is himself engaged. Accordingly, I contend that any presentation of acoustics entirely devoid of mathematics is an abandonment—and, so far as my observation goes, a needless abandonment—of an essential feature of the subject.

I think it is of the first importance that the material should be simple and interesting. The lecturer should never be in a hurry, nor should he feel that there is any set amount of material that must be presented in a given time. Herein the course differs from that usually offered to students majoring in physics! Members of the class will give hearty cooperation in demonstrating features and characteristics of musical instruments in which they are proficient. Direct questions and general discussions may be encouraged; students need not be individually catechized. The lecturer should be willing to revise his syllabus as he goes along, and should treat only topics that he fully understands, and firmly believes to be fascinating as well as fundamental. With these principles as a basis, any teacher contemplating the organization of such a course may confidently expect the "keen pleasure" to which Professor Stewart so happily refers.

CHAS. WILLIAMSON
Department of Physics
Carnegie Institute of Technology

Brief Notice of Recent Publications

Heat. JAMES M. CORK, Associate Professor of Physics, University of Michigan. Pp. 279+xi. Figs. 115. John Wiley and Sons, New York, 1933. Price $3.00. A textbook of intermediate grade in which lengthy descriptions of classical experiments have been avoided in order to make room for more modern material. There are many references to original papers. Elementary calculus is employed.

Differential Equations for Electrical Engineers. PHILIP FRANKLIN, Associate Professor of Mathematics, Massachusetts Institute of Technology. Pp. 299. Figs. 41. John Wiley and Sons, New York, 1933. Price $2.75. Designed for a one-semester course of junior grade. Contains many excellent problems, with answers.

Conduction of Electricity Through Gases. Vol. II. Ionisation by Collision and the Gaseous Discharge. J. J. THOMSON, Master of Trinity College and Professor of Experimental Physics, Cambridge, and G. P. THOMSON, Professor of Physics at the Imperial College of Science and Technology, London. Third edition. Pp. 608+vi. Figs. 240. The University Press, Cambridge, 1933. Price $6.50. The present volume completes the third edition of this standard treatise, originally published in 1903. Eighty-five percent of the material is new. Because of its wealth of experimental detail, the book has in the past proved to be of great value to beginners in research.

Instruction in Science. WILBUR L. BEAUCHAMP, Assistant Professor of Education, University of Chicago. Pp. 63+vi. Bull. No. 17. U. S. Office of Education, Washington, 1932. Price $0.10. (Paper cover.) One of the twenty-two monographs which report the results of the three-year national survey of secondary education recently completed under the direction of the United States Commissioner of Education.

ABSTRACTS

Abstractors for This Number: F. E. Knowles, Duane Roller, William Schriever, G. A. Van Lear, Jr.

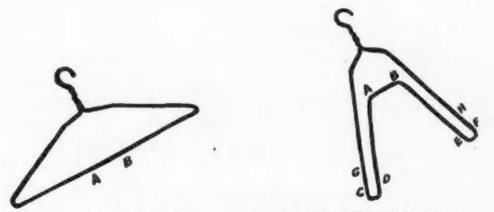
Apparatus, Demonstrations and Laboratory Practice

162. The versatile lantern slide. W. T. R. Price; *Ed. Screen* **12**, 159–160, 176, June, 1933. The development of hand-made slides in contrast with photographic slides has greatly increased the availability of lantern slides for instructional purposes. Some subjects which lend themselves to reproduction upon such slides are: original and copied drawings, tracings, mounted specimens, typed or printed tabulations and outlines. Etched glass upon which a hard pencil will produce the diagram or figure is perhaps the simplest material for making hand-made slides. India ink can be used upon glass but is less satisfactory than ordinary ink upon protectoid and traceoline. Protectoid (non-flour celluloid) is very satisfactory for ink drawings and is not expensive. D. R.

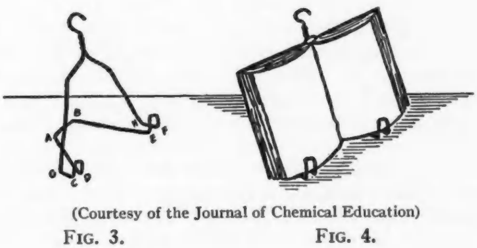
163. Improved process for physical development of plates, films, and lantern slides. Allan F. Odell; *Ind. and Eng. Chem. Ind. Ed.* **25**, 877–879, Aug., 1933. "Physical development . . . is to be distinguished from ordinary methods . . . by the fact that the developing bath contains a silver salt in solution from which colloidal silver is obtained by reduction with a suitable agent, also in the solution, and the production of the negative image results from the deposition of the nascent silver upon the silver nuclei forming in the latest image." The present article points out the unusual and little known merits of the method and describes an improved process which makes physical development as simple and successful in practice as ordinary methods of photographic development. This process has been applied to practically every make and type of plate on the market. "The extreme fineness of the grain size, coupled with the fact that this grain is formed independently of the grain of the original emulsion, constitutes the chief advantage of the method. One may thus use coarse-grain superspeed emulsions to obtain fine-grain images." The method should be of value in x-ray work, spectrum photography and microphotography. D. R.

164. Cleaning sodium metal. E. B. Wilson; *J. Chem. Ed.* **10**, 395, July, 1933. Slice the sodium into strips about a quarter of an inch thick, cover it with toluene in a flask, and heat the flask until the toluene boils and the sodium melts. The molten metal collects in a large globule and can be poured into a beaker, whereas the oxide, carbonate, etc, remain in the flask. The globule in the beaker can be broken into small pieces by rotating the beaker slightly before the globule has had time to solidify or by breaking up the plastic metal with a stirring rod. It is undesirable to attempt to filter the molten metal through wire gauze or glass wool. It may be siphoned directly from the flask into previously heated glass tubes if desired. Sodium will tarnish less if preserved under toluene rather than kerosene as the toluene is purer and absorbs water less readily than kerosene.
D. R.

165. Inexpensive laboratory manual rack. A. C. Adams; *J. Chem. Ed.* **10**, 414, July, 1933. An ordinary wire coat hanger is bent with a pair of pliers at the points A and B, Fig. 1, until it appears as shown in Fig. 2. Bends are then made at C and D, and E and F, to provide the ends for holding the book pages back. Finally, bends are made at G and H, in such a way that the supporting portion lies flat



(Courtesy of the Journal of Chemical Education)
Fig. 1. Fig. 2.



(Courtesy of the Journal of Chemical Education)
Fig. 3. Fig. 4.

on the table while the book-support inclines at a convenient angle with the table. Figs. 3 and 4 show the completed rack. D. R.

166. Simple cell for the study of conductance. H. B. Gordon; *J. Chem. Ed.* **10**, 440–441, July, 1933. Gives directions for constructing a cell for studying the changes of conductance which take place when two solutions are mixed, either with or without chemical change. The cell is made of wood and is separated into two horizontal compartments by a liquid-tight, but removable, wooden diaphragm. D. R.

167. Note on the filling of manometers. M. Q. Doja; *J. Chem. Ed.* **10**, 574, Sept., 1933. The manometer is joined by means of a piece of pressure tubing to the apparatus shown in Fig. 1. Stopcock A is closed, stopcocks D and B are opened and the apparatus is evacuated by means of a Cenco-hyvac pump. Freshly distilled mercury is then placed in the cup C, and stopcocks B and D are closed. A is then slowly opened and a small amount of mercury is al-

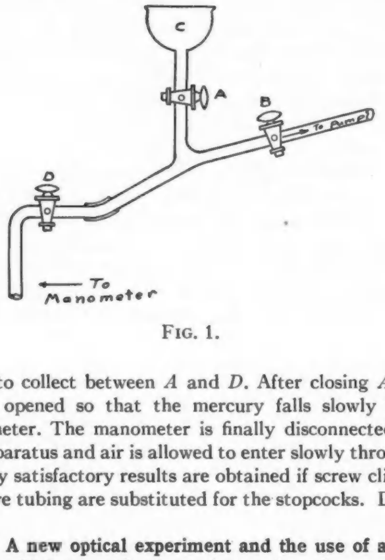


Fig. 1.

lowed to collect between A and D. After closing A, D is gently opened so that the mercury falls slowly in the manometer. The manometer is finally disconnected from the apparatus and air is allowed to enter slowly through D. Equally satisfactory results are obtained if screw clips and pressure tubing are substituted for the stopcocks. D. R.

168. A new optical experiment and the use of a single lens for high magnification; observation of entoptic and diffraction phenomena. J. Gibson Winans; *J. Opt. Soc. Am.* **23**, 289–292, Aug., 1933. Describes several interesting experiments for students which can be made with a camera and converging lens. These experiments can be used as an aid in locating flaws in lenses and flaws and particles within one's own eye, as a convenient method for studying Fresnel diffraction effects, and as a substitute for a microscope when high resolving power is not required. D. R.

169. A simple method of fitting fine cross-wires in an optical instrument. D. G. Drummond; *J. Sci. Inst.* **10**, 258–259, Aug., 1933. Place a small dab of liquid glue at the required point on the cross-wire ring, draw out the glue into a thin fiber with the tip of a pin and then, after allowing the fiber to harden for a moment, lower it across the aperture and fix the other end with a second dab of glue. The glue should be neither too thin nor to viscous. Straight, uniform fibers of thicknesses from 0.04 to 0.0001 mm are obtainable. The author comments on the behavior of various common brands of glue when used for this purpose. D. R.

170. The measurement of critical potentials with a screened grid valve. F. L. Arnot; *J. Sci. Inst.* **10**, 294–295, Sept., 1933. Experiments on critical potentials usually involve the construction of a special tube and elaborate high-vacuum system. This paper describes an instructive student-experiment on the determination of critical potentials of mercury vapor which employs the method of Davis and Goucher [*Phys. Rev.* **10**, 101 (1917)] and which can easily be carried out with the help of a sensitive galvanometer, a few cells and an ordinary four-electrode radio valve containing a trace of mercury. D. R.

171. Protecting tools and instruments from rust. Anon; *Pop. Mech.* **60**, 470, Sept., 1933. Directions are given for protecting tools from rust by use of fused calcium chloride or by coating them with a paste made of lard and rosin and benzine. Rust may be removed from such instruments as balances and micrometers by using a rust solvent made of oleic acid, ammonia and denatured alcohol. F. E. K.

172. Electric arc welder for the small shop. Clyde A. Crowley; *Pop. Mech.* **60**, 473–477, Sept., 1933. Gives instructions for making a transformer and other necessary parts for an apparatus with which one may weld metal up to 3/16 in. in thickness or rods as large as 1/4 in. in diameter. The device furnishes 60 volts at the arc and delivers a maximum of about 75 amp., and when operating draws about 28 amp. from the line. F. E. K.

173. Negative drier. Anon; *Pop. Mech.* 621–623, Oct., 1933. Gives complete details for constructing a "wind tunnel" which will quickly dry negatives suspended from a crosspiece at the top. F. E. K.

174. First aid for old books. Leslie H. Phinney; *Pop. Mech.* **60**, 755–758, Nov., 1933. Frequently it is the most valuable reference books in the laboratory that need rebinding. Advanced students or assistants would in many cases be glad to do the work if instructions were available. Such instructions, with drawings illustrating each important step, will be found in this article. F. E. K.

175. Sharpening your lathe tools. W. Clyde Lammey; *Pop. Mech.* **60**, 787–789, Nov., 1933. In this article the beginner at the lathe will find directions for sharpening tools. He is told how to hold the tools while grinding, given cautions about overheating, and furnished diagrams with the several bevels marked in degrees. F. E. K.

176. Bellows for homemade enlarging cameras. Anon; *Pop. Mech.* **60**, 790–791, Nov., 1933. Drawings and direc-

tions are given for making bellows for an enlarging camera. The materials needed are stiff cardboard about 1/16 in. thick, black sateen cloth and a little glue. F. E. K.

177. Electroplating with lead, zinc and cadmium. C. A. CROWLEY; *Pop. Mech.* **60**, 794–798, Nov., 1933. Gives complete directions for electroplating with cadmium, zinc or lead including the preparation of the surfaces, the solutions, the vats, and electrodes, and the proper voltages to be applied and time the current should be run. F. E. K.

178. Two simple methods of absolute measurement of electrical resistance in terms of inductance and frequency. H. R. NETTLETON AND E. G. BALLS; *Proc. Phys. Soc.* **45**, 545–554, July, 1933. The methods described in this paper may be simplified and readily performed by advanced students. "In the first method a sinusoidal alternating current of some 15 m.a. derived from a valve oscillator and of frequency equal to that of a König tuning-fork is allowed to induce an equal current in a secondary circuit. The equality of amplitude of the primary and secondary currents is judged with the aid of a Westinghouse instrument rectifier. The resistance of the secondary circuit is given by the expression $S=2\pi n(M^2-N^2)^{\frac{1}{2}}$, where n is the frequency, N the self-inductance of the secondary and M the mutual inductance between the primary and secondary. With standard forks of frequencies 256, 320, 384 and 512, resistances have been measured ranging from 16Ω to 67Ω. In the second method equal primary and secondary currents of known frequency are also produced and are further adjusted to be in quadrature. A simple arrangement is thereby derived which enables Campbell's two-phase alternating-current method of measuring resistance to be carried out in the laboratory. In both methods a visibly beating circuit is employed which enables the frequency of the current used to be tuned easily, with precision, to that of a valve-maintained fork. This beating circuit is also of value in checking the relative accuracy of forks whose frequencies are very approximately in simple ratio to one another." D. R.

179. The demonstration of eddy currents in conductors of various shapes. D. BROWN; *Proc. Phys. Soc.* **45**, 555–558, July, 1933. In teaching electromagnetic induction, demonstrations of the existence of eddy currents are usually of an indirect character, involving the resistance to motion of a mass of metal in a magnetic field or the rise in temperature of the metal. The method described in this paper makes it possible to demonstrate visually the existence of such currents in metal specimens, and the way in which the flow of the currents may be distorted or baffled by suitable slots or laminations. The experiment is easy to set up. D. R.

180. Frequency of the alternating current by visual method. DAVID L. COOK; *Sch. Sci. and Math.* **33**, 762–763, Oct., 1933. A standard lamp socket, containing a 110-volt neon bulb, is mounted on one end of a bar, and a counterweight is fastened to the other end. The bar is bolted at its middle point to a motor-driven rotator. Since the luminescence in neon gas is quenched at almost the same instant that the potential falls below a certain critical value, the speed of the rotator can be so adjusted that the lamp becomes bright at the same points in the circle in every revolution. Thus, for a 60-cycle current and 20 r.p.s., there will appear 6 bright spots corresponding to the 6 points in the path of the lamp where the potential has reached a maximum in either direction. Retinal fatigue causes each spot to appear as continuous. The number of cycles is equal to the number of rotations per second multiplied by one-half the number of spots. D. R.

GENERAL PHYSICS AND RELATED FIELDS

181. Lighting for effective seeing. L. V. JAMES; *Elec. Eng.* **52**, 543–546, Aug., 1933. "A non-technical explanation of the fundamental conceptions and relations underlying the application of lighting for effective seeing is given in this article. The tables and diagrams included should be useful in any study of illumination and intensity." D. R.

182. Radiation and evolution. JOHN LANGDON-DAVIES; *Forum* **90**, 214–217, Oct., 1933. This article should be of interest to any one who desires general information regarding the growing field of bio-physics or the new applications of radiology. The article calls attention to experiments in which x-rays applied to plants and insects, in particular the fruit fly, have brought about changes which may help to determine the cause of variation. The method of patient waiting for results through long periods of observation used by those following Darwin and Mendel may now be supplemented by a process of speeding up by use of radiation. F. E. K.

183. Diffusing glasses for illumination. HENRY H. BLAU; *Ind. and Eng. Chem. Ind. Ed.* **25**, 848–853, Aug., 1933. The topics discussed are: physics of light scattering; factors influencing light scattering; spontaneous and controlled formation of crystallites; applications of controlled crystallization. It is found that glasses which diffuse the light by means of their internal structure (inclusions within the glass) have outstanding illuminating advantages over those which diffuse light as a result of surface irregularities. The author is connected with the Macbeth-Evans Glass Company. D. R.

184. Absorption spectra of gaseous changes in a gasoline engine. LLOYD WITHROW AND GERALD M. RASSWEILER; *Ind. and Eng. Chem. Ind. Ed.* **25**, 923–931, Aug., 1933. An apparatus is described that photographs absorption spectra of the gases within an internal combustion engine running under its own power. The spectra show that under some engine conditions chemical changes occur in the fuel-air

mixtures prior to inflammation. Such changes are greater in degree or different in nature in knocking than in nonknocking combustion. The idea is supported that knock is due to spontaneous ignition ahead of the normal flame fronts.
D. R.

185. Substitute for equivalent weight. CHARLES N. OTT; *J. Chem. Ed.* **10**, 312, May, 1933. The equivalent weight of an element (or compound) is obtained by dividing its atomic (or molecular) weight by its active valence. The author suggests that the term *equivalent weight* be replaced by *univalent weight* since it actually represents that weight of an element or compound which might be considered to have a valence of 1. D. R.

186. Some physico-mathematical aspects of nerve-conduction. N. RASHEVSKY; *Physics* **4**, 341–349, Sept., 1933. It has been shown previously by the author that, from the physical point of view, the process of propagation of the nerve impulse is essentially different from the propagation of other kinds of disturbances usually studied in physics. Instead of being described by a differential equation, this type of propagation leads to a simple integral equation. In the domain of the inorganic similar types of propagation are met in the spread of activation on the surface of passive metals. In the present paper the problem of such types of propagation is treated mathematically for two different cases. In the first case it is assumed, that the nerve is electrically uniform all along its length. In this case the final formula for the velocity of propagation reduces to a rather simple expression which applied to the ischiadicus of the frog, leads to a value of 15 $\text{m}\cdot\text{sec.}^{-1}$ for the velocity of propagation. In the second case the nerve sheath is assumed to be completely insulating, except at the Ranvier nodes, where its continuity is broken, so that the electrical properties of the nerve vary periodically along its length. For the second case a more complicated formula is obtained, which reduces to the first one, when the distance between the nodes tends to zero. Effects of possible distributed capacity are briefly discussed. (The author.)
D. R.

187. Short waves I have known. ZEH BOUCH; *Radio Fan-fare* **30**, 21–47, Sept., 1933. Compares the entertainment value of short-wave reception with that of the broadcast band. Police broadcasts, amateur radio telephone conversation, programs that are given on both short wave and broadcast bands, and trans-oceanic telephony are considered. F. E. K.

188. Short-wave Fan-fare. ZEH BOUCH; *Radio Fan-fare* **30**, 40, Oct., 1933. The first two columns of this article will help the physics teacher to answer questions regarding the comparative merits of adapters, converters, single-control superhetrodyne, and all-wave receivers for short-wave reception. F. E. K.

189. Teaching highway safety through high school sciences. HERBERT J. STACK; *Sch. Sci. and Math.* **33**, 746–750, Oct., 1933. The author points out that physics instruction may make a distinct contribution to traffic safety and cites a number of problems that are of value for this purpose. Examples are: From what height would an automobile have to be dropped in order to acquire momentum of the same magnitude as that of an automobile travelling 60 $\text{mi}\cdot\text{hr.}^{-1}$? If an automobile travelling 30 $\text{mi}\cdot\text{hr.}^{-1}$ moves 40 ft. before stopping after the brakes are applied, how far will it move before stopping when the speed is doubled? What are the best methods of bringing a car to a stop that has started skidding going down a slippery hill? What is the best kind of lights to use in a heavy fog? D. R.

190. Measuring the counterglow (Gegenschein). HENRY NORRIS RUSSELL; *Sci. Am.* **148**, 278–279, May, 1933. The origin of the counterglow and zodiacal light is explained and suggestions for observing it are given. W. S.

191. The secret message of the cosmic rays. ARTHUR H. COMPTON; *Sci. Am.* **149**, 5–7, July, 1933. Brief popular review. Well illustrated. W. S.

192. The amateur and his microscope. I. ERNEST H. ANTHES; *Sci. Am.* **149**, 18–19, July, 1933. The first of a series of authoritative, nontechnical articles on the microscope and its uses, prepared by members of the Bausch and Lomb Optical Company. W. S.

193. Uranium as the earth's clock. ALOIS F. KOVARIK; *Sci. Mo.* **36**, 363–365, April, 1933. A Science Service Radio Talk, in which the facts of radioactivity pertinent to the problem of determining the ages of radioactive minerals are presented, the line of reasoning outlined, and the results obtained in two cases given as 1852 million years and 850 million years, respectively. G. A. V.

194. On the research work of the U. S. Weather Bureau. W. J. HUMPHREYS; *Sci. Mo.* **36**, 419–428, May, 1933. The routine work of the Bureau is described briefly, but particular attention is paid to partially-solved and unsolved problems. Many of these are mentioned and the present status of each is indicated. G. A. V.

195. Earthquakes—what are they? JAMES B. MACELWANE; *Sci. Mo.* **36**, 457–460, May, 1933. The principal facts about earthquakes are related, and what seems now to be their most probable cause explained. "For the present, we must be satisfied with knowing that it is an elastic process; . . . , and that it is probably produced by the sudden release of a regional strain within the crust of the earth." This article is the text of a Science Service Radio Talk.
G. A. V.

196. The fundamental units of the physical world. RUDOLF W. LADENBURG; *Sci. Mo.* **36**, 465–467, May, 1933. An extremely condensed account is given of the current work and recent discoveries in the field of nuclear physics, including the discovery of the positron. G. A. V.

197. The work of the National Bureau of Standards in metrology and mechanics. Lyman J. Briggs; *Sci. Mo.* **36**, 502–511, June, 1933. A brief survey of the work of the Bureau in metrology and mechanics is given under the following headings: weights and measures, testing engineering instruments and mechanical appliances, aircraft instruments, wind tunnel investigations, testing fabricated structures, national hydraulic laboratory, acoustical laboratory. Ten illustrations show instruments and equipment employed in the work described. G. A. V.

Intermediate and Advanced Physics

198. Contemporary advances in physics, XXVI, the nucleus, first part. Karl K. Darrow; *Bell Sys. Tech. J.* **12**, 288–330, July, 1933. This article, like its forerunners on radioactivity and transmutation, is devoted to the beginnings of the oncoming stage of atomic physics: the study of the nucleus. The nucleus or kernel of an atom is in ultimate control of all its properties and features, for such of these as do not depend directly on it depend upon the number and arrangement of the orbital electrons, both of which are decided by the nuclear charge; further, the atomic weight is decided almost exclusively by the nuclear mass. Though in dealing with most of these properties it is usual to imagine the nucleus as a geometrical point endowed with mass and charge, the truth is far less simple and more interesting. Nuclei are structures built of elementary particles—some and maybe all of which are independently known to us—bound tightly together. It is of great importance to ascertain these structures, not only for their own sake, but because through understanding them we may become able to control and extend the transformations of nuclei from one kind to another—the processes of transmutation, some of which are already feasible. Several fields of research are apt to contribute to such an understanding. Accurate measurement of the masses of atoms, and of the masses and charges and other properties of the elementary particles, are the first two of these, and form the subject of the present article. (The author.) D. R.

199. Short cuts for finding $(a^2+b^2)^{\frac{1}{2}}$. W. J. Seeley; *Elec. Eng.* **52**, 583–584, Aug., 1933. Enumerates several approximation methods for finding $(a^2+b^2)^{\frac{1}{2}}$ with determinable accuracy, so that the computer may select the method which best suits his needs. D. R.

200. A study of the velocity of sound in air. Martin Grabau; *J. Acous. Soc. Am.* **5**, 1–9, July, 1933. This study of the velocity of sound in air involves the use of the magnetostriction oscillator in an experiment similar to those of G. W. Pierce and others, who used piezoelectric crystals as sources of sound. The wave system generated by the source is investigated by observing the reactions of the source when the sound waves are reflected back upon it from a movable reflector. The range of frequencies used extends from 20,000 to 70,000. The irregularities of the wave system near the source are studied in some detail. It is found that these irregularities vary with the frequency, as well as with the diameters of both the source and the reflector, and that they vanish at relatively large distances from the source. The values of the velocity of sound then obtained show no variations with respect to the frequency. (The author.) D. R.

201. The Angstrom. Lyman J. Briggs; *J. Frank. Inst.* **216**, 541–542, Oct., 1933. In view of the present general practice of expression optical wave-lengths in terms of the *international Angstrom*, the Bureau of Standards has adopted the practice of representing this unit by the symbol 'A'. Where the Rowland scale of wave-lengths is intended it should be specified as such. The *Angstrom* is equal to 1/6438.4696 of the wave-length of cadmium red radiation, and within the limits of the most refined measurements known, this value is identical with the definition 1 Angstrom $=10^{-10}$ m. D. R.

Philosophy of Science

202. Science has not gone mystical. Henshaw Ward; *Atlantic Mo.* **152**, 186–194, Aug., 1933. An attempt is made to dispel the popular impression that science—physics in particular—has left the field of common sense to roam in the fields of metaphysical speculation. The checks and balances within each science which serve to keep it sound are pointed out, with illustrations drawn from both physics and biology. Particular attention is paid to recent attempts to draw philosophical conclusions from Heisenberg's uncertainty principle.

Comments by the abstractor: Although written by a layman for other laymen, this article provides worth-while, sound, and pertinent reading for physics students at all stages. Its emphasis on the rôles played by experimental facts and hypotheses in the working of the scientific method should prove quite valuable. G. A. V.

203. Science changes its mind. Waldemar Kaempffert; *Forum* **90**, 104–108, Aug., 1933. The author gives an outline of the transition in thinking from the "old Victorian machine universe" to the latest "set of mathematical equations." He considers such concepts as force, electrons, photons, atomic structure, time and space, and discusses the validity of cause and effect, the second law of thermodynamics, conservation of matter, the expanding universe, the principle of uncertainty and free will. A place in the progress of thinking is accorded to the poets and the theologians. F. E. K.

AUTHOR INDEX TO VOLUME 1

In this author-index are listed the names of the authors and the titles of their articles. Authors of abstracts which appear in the abstract section of the journal are not included. Abstracts will be found indexed in the *Analytic subject index.*

ANALYTIC SUBJECT INDEX TO VOLUME 1

In this subject-index, the titles of articles and of abstracts are disregarded, the entries being based on analyses of the contents of the original articles and abstracts. Entries marked (A) refer to abstracts which appear in the abstract section of the journal; entries marked (R) refer to reviews.